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Industrial Fumigation Against Insects

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UNITED STATES DEPARTMENT OF AGRICULTURE

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Industrial Fumigation Against Insects[1]

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INTRODUCTION

Insect infestation is frequently a problem of considerable importance in the storage of many types of merchandise. During warm weather or in heated buildings, foodstuffs, cereals, seeds, tobacco, furs, fabrics, etc., are highly susceptible to infestation by insects, and heavy losses are likely to occur unless adequate protection is given

[1] Charles M. Fergusson, safety engineer of the Department, has made numerous suggestions for the safety of the fumigator, which have been incorporated throughout the text. For fumigation safeguards see p. 59.

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them. If cold-storage facilities are available, such commodities can be protected from insect damage by holding them at temperatures below 45° to 50° F. Many times, however, it is impossible or impractical to use cold storage, and it is necessary to resort to fumigation.[2] This circular describes various methods by which products in storage or the establishments in which they are manufactured can be protected from insect attack by the use of fumigants.

In the protection of stored commodities four methods of fumigation are in common use: (1) The general or large-scale fumigation of warehouses and mills (fig. 1), (2) vault fumigation (fig. 2), (3) bin fumigation (fig. 3), and (4) vacuum fumigation (fig. 4).

FIGURE 1.—Interior view in flour mill ready for fumigation with hydrocyanic acid gas generated by the barrel method. The eight barrels containing the acid-water mixture stand in galvanized-iron washtubs, and a sack of sodium cyanide is ready to be lowered into each barrel. **Men lowering these sacks into the barrels, or working in any capacity around this or similar operations, should wear an approved gas mask and oiled leather gloves.**

Each method is adapted to a certain type of work and will be discussed separately. In most industries a combination of two or more of these methods can be used to advantage; and sometimes special methods, such as fumigation under tarpaulins (fig. 5) or the treatment of the individual pack of a commodity (fig. 6), are developed.

[2] The Division of Insecticide Investigations of this Bureau states (August 1942) that there are ample supplies of all the fumigants mentioned in this circular except carbon tetrachloride and ethylene dichloride. Owing to war priorities these two will be available for fumigation purposes only in restricted amounts unless the War Production Board can be convinced that their use is essential to the conduct of the war. There may develop a shortage of copper tubing for liquid hydrocyanic acid fumigation of large buildings and of steel for the construction of vacuum fumigators.

GENERAL MILL OR WAREHOUSE FUMIGATION

All mills, factories, warehouses, and storage rooms in which material subject to insect attack is handled become infested at one time or another and need a general fumigation. The managers of many such places realize the importance of maintaining a clean plant and fumigate one or more times a year as a general practice. Others, fearing the trouble and expense, wait until conditions become so bad that they are forced to shut down their mills for a thorough cleaning and fumigation.

There is no reason why fumigation should be an expensive operation, as with simple equipment and under the supervision of an experienced man a few intelligent workers can be quickly trained to fumigate most places with no more expense than their time and the bare cost of the materials.

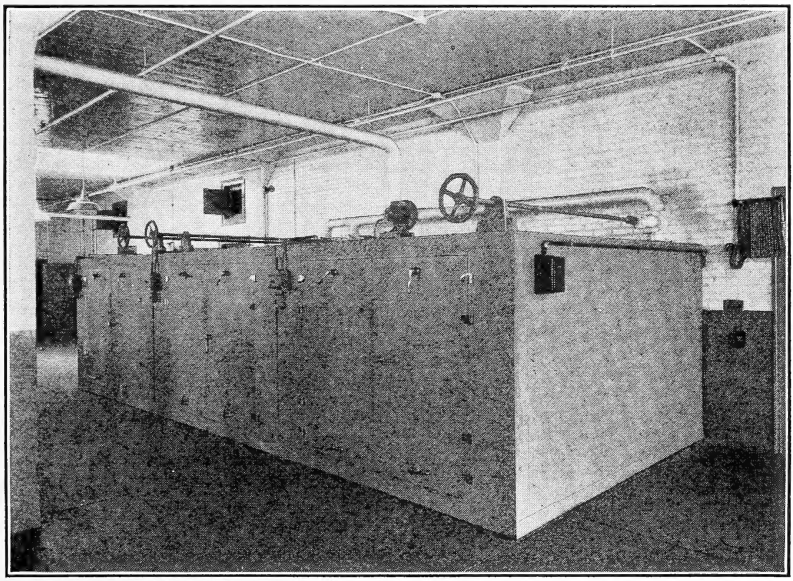

FIGURE 2.—A battery of three modern steel fumigation vaults, each about 6 by 8 by 10 feet, equipped with apparatus for introducing and withdrawing the fumigant, and for heating and circulating the air within. Such vaults are used for treatment of various commodities, in this instance furs, and not ordinarily for continuous storage.

REQUIREMENTS FOR A SUCCESSFUL FUMIGATION

Success in the fumigation of any large building or enclosure depends upon the proper planning and execution of the work, the careful preparation of the building, and the correct choice of the fumigant and time of its application. The building must be made as nearly gastight as possible in order to avoid waste of gas and to retain a lethal concentration of the fumigant as long as possible. All machinery or special pieces of apparatus must be cleaned and opened up to allow maximum penetration of the gas.

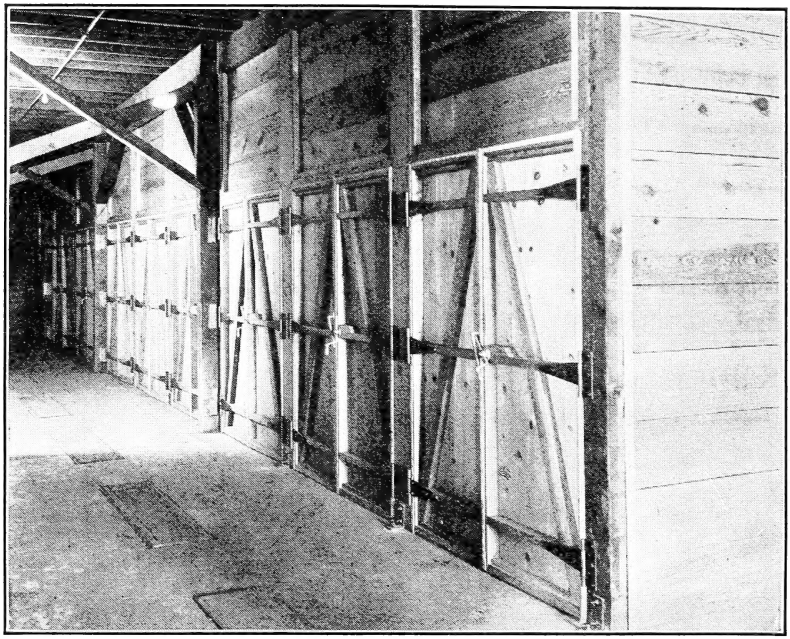

FIGURE 3.—A battery of 10 storage bins so constructed that dried-fruit products stored in them can be fumigated.

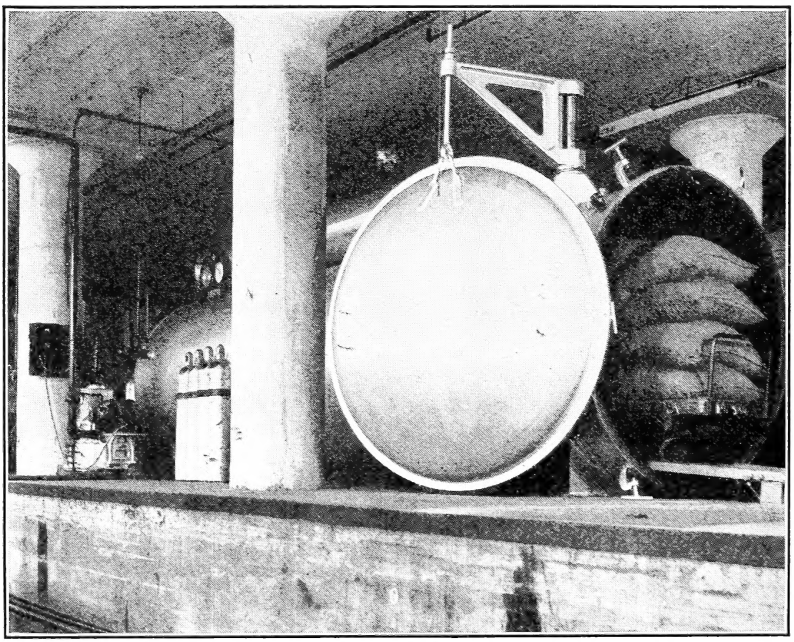

FIGURE 4.—A vacuum fumigating unit in a large general-merchandise storage warehouse. Since it is located along the railroad siding, susceptible commodities are fumigated as they are unloaded from the freight car and before they are placed in storage rooms, where only fumigated supplies are stored.

The temperature must be high enough to render the insects susceptible to the fumigant and to allow for its most efficient action.

The fumigant must be suitable for the building in which it is used and for the contents of the building. The quantity must be

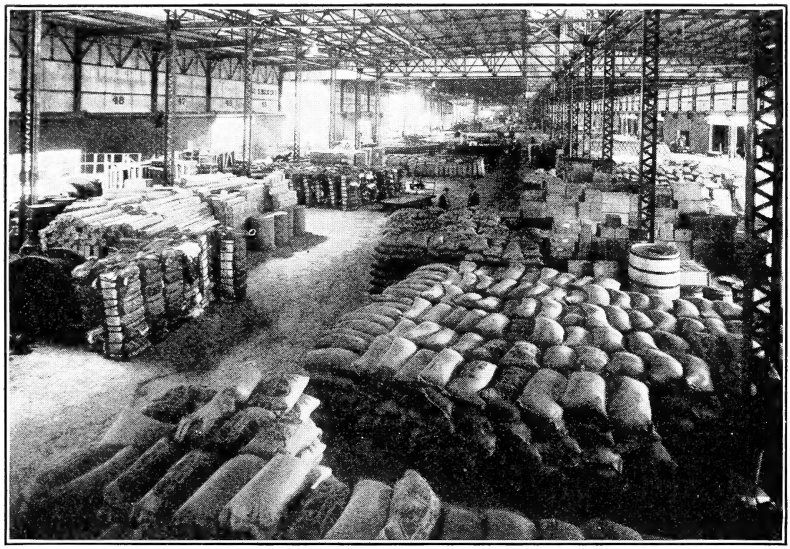

FIGURE 5.—Commodities of various types assembled for export on a modern dock. Carload lots of supplies found slightly infested upon arrival by rail are sometimes fumigated beneath rubberized tarpaulins.

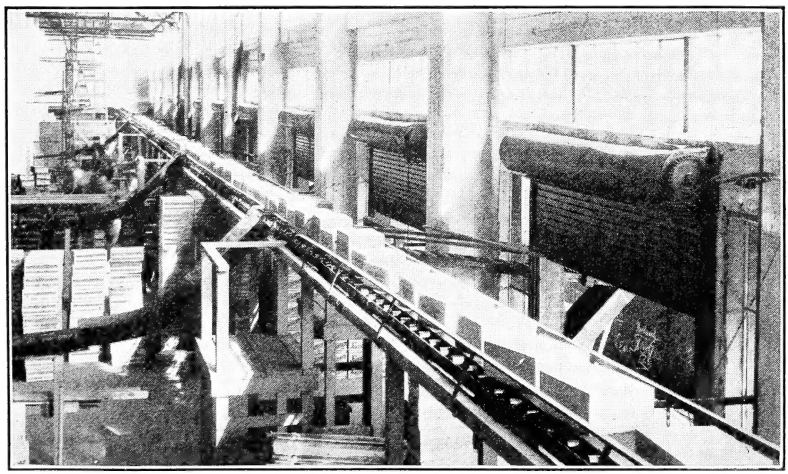

FIGURE 6.—While industry in general has not found it feasible to promote insect sanitation by introducing a fumigant into the shipping unit as it moves through the packing machinery, this is a method that has been satisfactorily employed. The fumigant, in liquid form, is automatically introduced in each container just previous to the entry of the commodity and the sealing of the container.

great enough to allow for the loss through poor construction of the building, absorption by the contents of the building, and adverse weather conditions. The fumigant must also be properly applied and distributed. The exposure must be long enough to permit maximum penetration and killing effect.

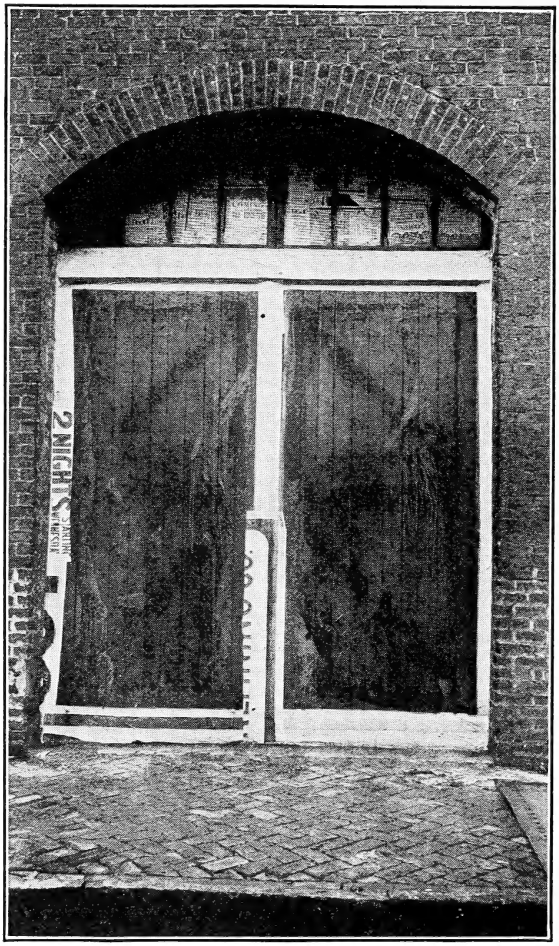

FIGURE 7.—Doors to warehouse, and transom, sealed with old advertising posters cut into strips. Latticed warehouse doors in warm climates can be effectively sealed with three or four thicknesses of such material.

PREPARING THE BUILDING FOR FUMIGATION

It is essential that the building be made as nearly gastight as possible. A modern concrete building having windows with steel frames is excellent for fumigation purposes, since little effort is needed to make it reasonably gastight. Doors leading to the outside should be sealed (fig. 7). Ventilators on the roof (fig. 8) or outside walls should also be sealed over, and any windows that are not tight should be sealed around the edges.

Old or poorly constructed buildings present a different problem. Both walls and roof must be carefully inspected for cracks or breaks. In certain types of roofs the union between the roof and the walls may be faulty and need to be tightened (figs. 8 and 9). Any loose flashing around chimneys and ventilators must be repaired, and ventilators and skylights must be sealed over (fig. 8). In some cases it is impossible to tighten a window by the ordinary method of wedging and sealing or stripping, and the entire aperture must be sealed over (fig. 9). For this purpose a fiber-reinforced waterproof building paper is excellent. It can be obtained in rolls 300 feet long and from 3 to 7 feet wide. It is a simple matter to tack it over the opening, and the edges can be sealed down with adhesive tape.

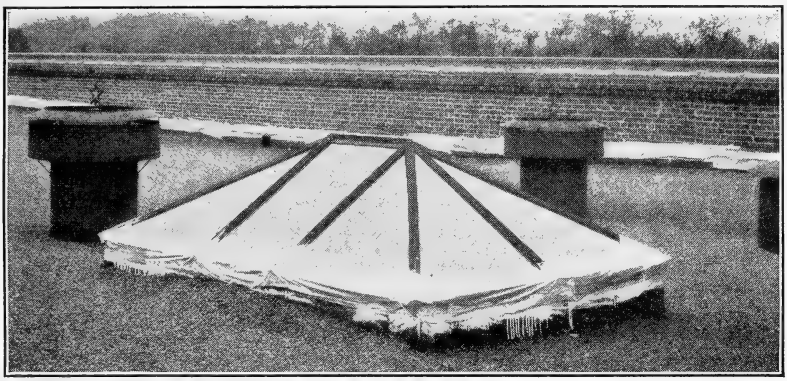

FIGURE 8.—Skylights and flashings on roof sealed in preparation for fumigation. All ventilators must also be sealed.

If this type of paper is not available, any good tough paper can be used and can be applied by a paperhanger or any careful workman. Even newspapers or old advertising posters will sometimes suffice if several layers are used, but the best paper for fumigation purposes is that impregnated with fiber and tar.

Loosely fitting window sashes should be sealed with paste and paper, or puttied up with a mixture of flour and oil. For stripping windows that are only slightly loose several types of materials can be used. Rolls of gummed paper, strips of newspaper smeared with grease or pasted with flour paste, and rolls of unsterilized adhesive or masking tape, known as "fumigators' tape," all have their place.

Small doors leading to the exterior of the building can be tightened by stripping around the edges with any of the materials used for the windows. Large sliding or hinged doors that fit imperfectly, or elevator-shaft openings, can be sealed most effectively by forcing a framework of 2- by 4-inch lumber covered with fiber-reinforced waterproof paper against strips of heavy felt padding (figs. 10 and 11). Such a sealing can be used many times. Another method is to calk the doors with a paste composed of 4 parts of asbestos fiber to 1 part of calcium chloride mixed with a little water. The calcium chloride will absorb enough moisture from the air to keep the paste pliable and thus insure a tight seal. It is a cheap yet effective sealing material and can be easily removed after the fumigation.

Machinery that is used to pack, mix, or handle foodstuffs in any way should be opened as completely as possible and all accumulations of materials removed. Most fumigants do not penetrate for more

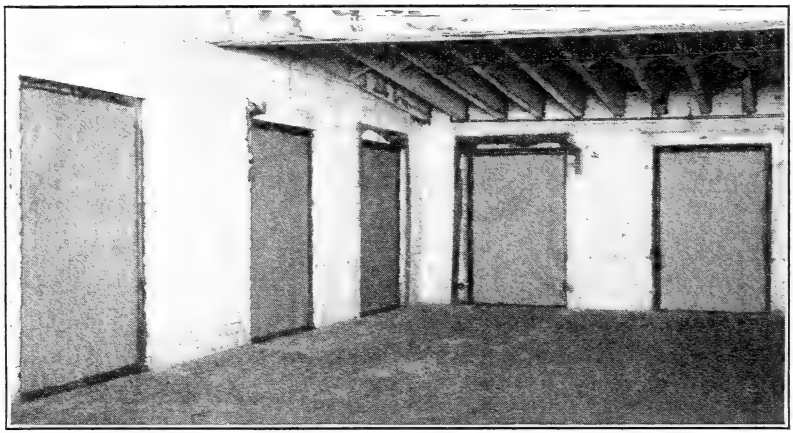

FIGURE 9.—Windows sealed on the inside with paper. Cracks about unions of rafters and walls are sealed with plastic cement.

than a few inches into flour, meal, or similar foodstuffs; hence, such accumulations, if left in the machinery, protect insects from the effects of gas. Accumulations of waste material under or around

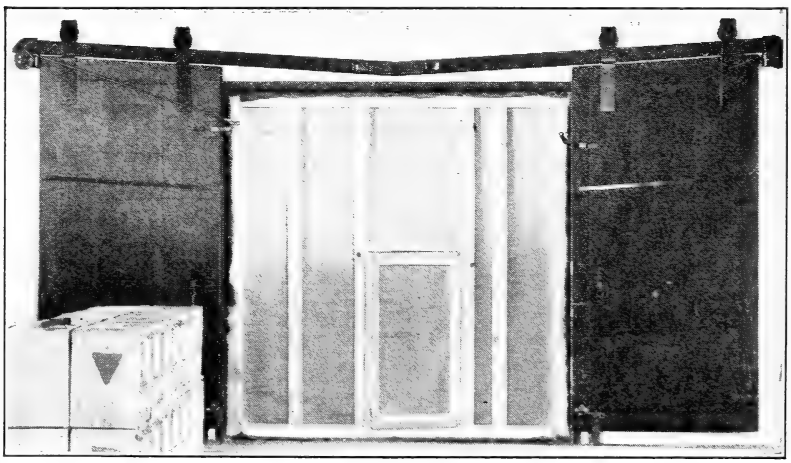

FIGURE 10.—Doorway between compartments in modern concrete storage warehouse sealed for fumigation. Framework of 2- by 4-inch lumber, covered with heavy fiber-reinforced waterproof paper, forced against strips of heavy felt padding. The fireproof doors have been rolled back. Note the small door, which also shuts against felt gaskets, for the use of fumigators. A glass window has proved useful in permitting inspection of operations.

machinery, in feed bins, or in any part of the building should also be removed and sold or destroyed before fumigation.

Commodities in warehouses or storage rooms should be so arranged as to provide the maximum circulation of the fumigant; large, solid

stacks of bagged material should be avoided. In sections that are divided into small compartments or storage rooms, the connecting doors should be opened to allow a proper distribution of the gas. Where sections of a floor are large, as in many metropolitan storages, each section may be fumigated to better advantage as a single unit.

Desirability of a High Temperature During the Fumigation

It is desirable to maintain a fairly high temperature in the building during the fumigation. Insects are not very active at temperatures below 60° F., and they become more or less dormant at 50° or

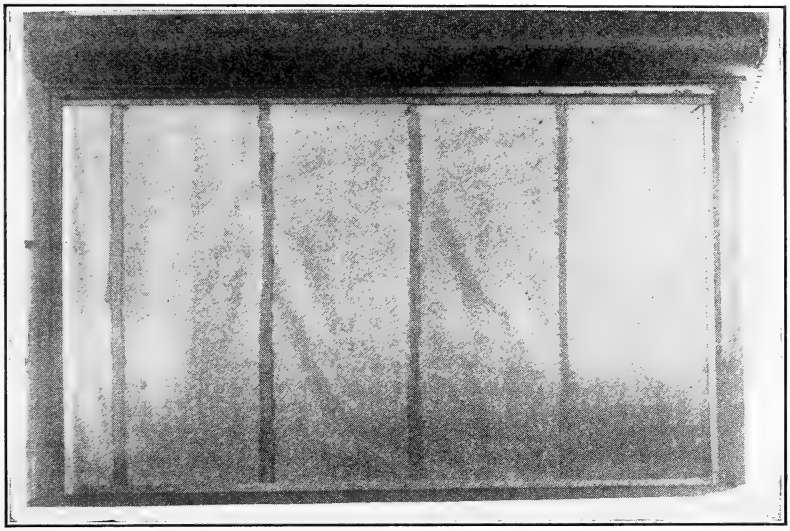

Figure 11.—Opening to elevator shaft sealed ready for fumigation in same manner as the doorway in figure 10. In both cases the sealing was done at the Naval Supply Depot, Naval Operating Base, Hampton Roads, Norfolk, Va.

below. In the dormant state they are extremely difficult to kill with fumigants. At 75° they are active and their susceptibility to the gases increases as the temperature rises. For best results a temperature of at least 75°, and preferably somewhat higher, should be maintained throughout the fumigation.

Effect of Wind Velocity

The velocity of the wind during the exposure influences the effectiveness of a fumigation. The fumigation should be conducted preferably when there is no wind, since recent work has shown that in a building of ordinary construction a strong wind will force a large portion of the fumigant away from the windward side and so prevent a uniform distribution of the gas.

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Effect of Light or Darkness

Light and darkness have no appreciable effect upon the results of a fumigation. Although insects are more quickly affected while they are active, entirely satisfactory results follow the application of a fumigant during the day when the insects, such as cockroaches and bedbugs, are chiefly resting in hiding places. In general professional fumigators work at times most convenient to the establishment to be fumigated without thought of light or darkness. In the case of an insect such as the cockroach that forages in the dark, more individuals may be killed by a night fumigation if the daytime hiding places are in wall spaces difficult of gas penetration. Usually, however, hiding places of insects in commercial plants are easily penetrated by fumigants, and the time of day the fumigant is applied is therefore unimportant.

Choice of a Fumigant

In choosing a fumigant several factors must be taken into consideration. If the building is modern and very tight, several fumigants can be used with success, and a choice can be governed by such items as cost, efficiency, availability, safety, and effect upon the commodity to be fumigated. If the building is not particularly tight, it will be impossible to maintain a strong concentration of any gas for very long, and a quick-acting gas is the only kind that will be effective. Hydrocyanic acid is the only gas available that will kill quickly.

Quantity of Fumigant Needed

The quantity of fumigant to be used will vary according to the length of exposure, the temperature, the tightness of the building, the amount of absorption and adsorption by the commodities to be fumigated and by the walls and floors of the building itself, and the insect to be eradicated. The shorter the exposure, the lower the temperature, the looser the construction of the building, the greater the absorption and adsorption, and the more resistant the insect, the greater must be the dosage. The fumigator must exercise his own judgment in each case.

Applying the Fumigant

The fumigant should be applied in such a way that a maximum concentration will be obtained as quickly as possible. Since most commercial establishments are not airtight, the natural leakage from a building is often great enough to prevent a killing concentration from ever being attained, particularly if it takes considerable time to reach that concentration. From some buildings fumigants escape so rapidly that it is not practical to fumigate them. In buildings that can be fumigated with reasonable expectation of success, the best results are obtained by releasing the entire dosage at the beginning of the fumigation.

A uniform concentration will be obtained more rapidly if the fumigant is distributed equally throughout the building. When using lighter-than-air gases it is not necessary to place the heaviest dosage

on the lower floors, since gas concentrations tend to become equalized in all parts of the building shortly after the fumigant is introduced. **The fumigant should be applied from the outside if possible, and the fumigation crew should be supplied with gas masks having canisters designed for protection against the gas to be used. Even when the equipment used in applying the gas is outside the bin or building, leaking connections, broken tubing, and gas leaking from the bin or building are encountered so often that protection is necessary at all times.**

Before the fumigation is started, the building should be thoroughly searched to make sure that no workmen or visitors are inside. During the fumigation all entrances to the building should be kept locked and usually guarded by watchmen. Placards warning people to keep out should always be tacked on all doors. Each operator should be familiar with the entire plan of procedure as well as with his own particular job. The entire operation should be under the supervision of a thoroughly experienced man ready to give assistance in case anyone gets into trouble. Help given at the right time will prevent possible fatal accidents.

Ventilating the Building After Fumigation

After the fumigation the building should be aired out by opening doors and windows, if possible from the outside. Wherever it is necessary to open certain windows from the inside, all openings accessible from the outside should be opened first, and the building aired out as well as possible by that means before men (wearing gas masks) are permitted to enter, for concentrations of gas higher than the capacity of the gas-mask canister are frequently encountered under these conditions. The skin of the operators should also be completely protected, since many of the fumigating gases are absorbed through the skin. It is important that watchmen be instructed to prevent anyone from entering the building while it is being ventilated. A large proportion of the fatalities connected with fumigation have been due to criminal neglect on the part of watchmen.

Fumigation With Hydrocyanic Acid Gas

For the fumigation of large buildings there is no more efficient gas than hydrocyanic acid. It is relatively inexpensive, kills with great rapidity, and, although deadly poisonous, can be handled with reasonable safety by experienced men. It can be used in nearly all types of buildings and will not injure most articles of commerce.

Hydrocyanic acid gas is commonly produced in one of four ways: (1) By generating it in a barrel, earthenware crock, or other container from a mixture of sodium cyanide, sulfuric acid, and water—the so-called barrel or pot method; (2) by pumping it into the building or machinery in liquid form from cylinders—the liquid method; (3) by spreading on the floor of the building an absorbent material saturated with liquid hydrocyanic acid—the discoid method; (4) by spreading on the floor of the building a powder consisting of calcium cyanide,

which combines with moisture from the air to form hydrocyanic acid gas—the powder method.

THE BARREL OR POT METHOD

The barrel or pot method of generating hydrocyanic acid gas is so called because the chemicals used are placed together in a barrel (figs. 1 and 12) or some similar container (fig. 13). This method, while

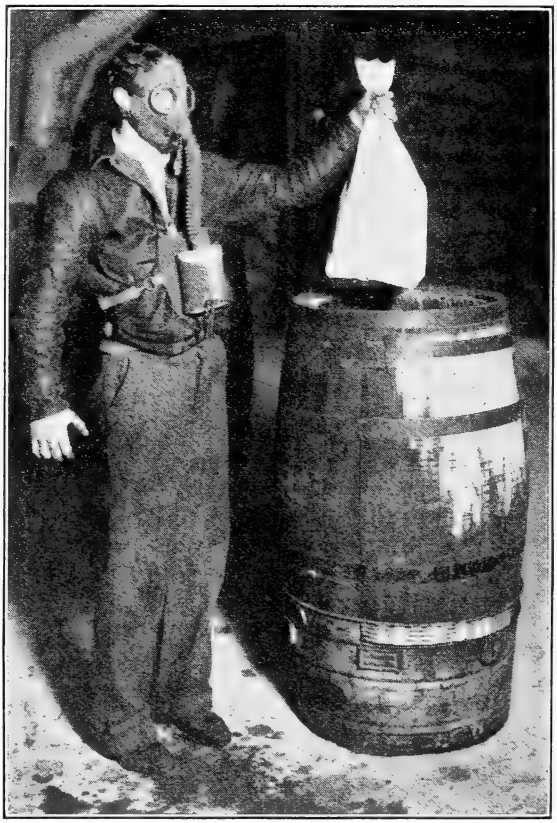

FIGURE 12.—Man wearing gas mask about to lower bag of sodium cyanide into a barrel containing sulfuric acid and water. If the cyanide is put in a gunny sack, there is no danger of the bottom of the bag breaking and spilling the cyanide. The cyanide should not be dropped into the acid-water mixture; it should be lowered carefully.

more laborious than others, gives excellent results and is the safest for the use of other than professional fumigators. It can be made the cheapest method of fumigation.

CHEMICALS REQUIRED

Sodium cyanide (96 to 98 percent, containing 54 percent HCN), a commercial grade of sulfuric acid (66° B.), and water are the only materials required. Sodium cyanide is a white crystalline sub-

stance, which for fumigation purposes is prepared in egg-shaped lumps weighing approximately ½ or 1 ounce each. It is a violent stomach poison, and can also cause serious poisoning by being absorbed through open cuts on the hands. For this reason it is best handled with a scoop or shovel. The hands should always be protected.

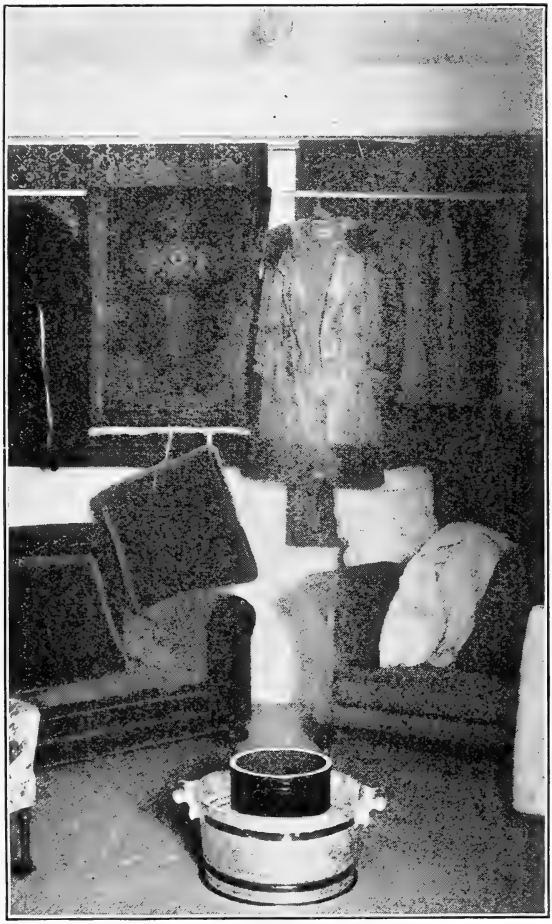

FIGURE 13.—Crock for the generation of hydrocyanic acid gas by the pot method, set in a galvanized-iron tub to prevent injury to the floor in case the crock cracks.

Pure sulfuric acid is a heavy, colorless liquid, but the commercial acid used in large-scale fumigation work is slightly colored, or murky, owing to impurities. It is highly corrosive and will cause injury if it is spattered on the clothing or body of the operator or upon the floor. Sulfuric acid can be purchased in 11-gallon carboys or in smaller quantities in glass bottles. Glass bottles containing the acid should be packed in a wooden box or paper carton to prevent breakage. When large quantities of acid are required, a tilting frame

will be found convenient in pouring the acid from the carboys. Workmen should learn to pour acid slowly and with caution, for their clothing or shoes will be damaged if a drop of acid falls on them. It is well to have easily accessible a pail of water in which some washing soda has been dissolved, for quickly washing away droplets of acid that may spatter on face, hands, or clothing. A sulfuric acid pump that can be attached to a carboy is somewhat slower but easier to handle.

All men handling the dry sodium cyanide and mixing the acid and water should wear oiled gloves and tight-fitting goggles. The workers who place the bags of sodium cyanide in the acid and water mixture should also wear gas masks equipped with the proper canister for this gas.

For best results the chemicals should be mixed according to the following formula:[3]

Sodium cyanide	pound	1
Sulfuric acid	pints	1½
Water	do	3

Proper Order of Placing Chemicals in Generator

To generate hydrocyanic acid gas by this method, the operator should first pour the water into the generator and then add the acid. If the procedure is reversed, the reaction is so violent that the operator may be dangerously burned by the spattering of the acid-water mixture. The sodium cyanide is not added to the mixture of water and acid until everything is in readiness for the fumigation, as it causes an immediate chemical reaction in which hydrocyanic acid gas is given off (fig. 14). The pure gas is colorless, but when mixed with steam produced by the chemical reaction it has the appearance of a light bluish smoke. It has an odor resembling that of peach kernels.

Dosage

The dosage is computed on the basis of the quantity of sodium cyanide required. For general mill or factory fumigation where no large quantities of materials are stored, 1 pound of sodium cyanide will produce enough gas to fumigate 1,000 cubic feet of space, if the building is of reasonably tight construction. If the building to be fumigated is filled with merchandise, the dosage required will vary according to the nature of the merchandise. Dosages have been computed for the fumigation of the more important commodities and will be discussed in a later section of this circular.

THE GENERATOR

For large-scale fumigations a water-tight 50-gallon wooden oil barrel (figs. 1, 12, and 14) is the most suitable generator to use. Metal barrels are not satisfactory. Barrels in which paint, glue, molasses, pitch, etc., have been stored should be avoided, for when the acid is added it may eat out these materials from between the staves, thus causing a barrel thought to be liquid-tight to leak. Barrels

[3] Chemical tests indicate that a 1–1½–2 formula yields more gas than the 1–1½–3 formula here recommended. The smaller quantity of water often results in a crystallization of the residue which makes the emptying of the containers after fumigation more difficult. In general large-scale work the authors have found the 1–1½–3 formula more practical and the results satisfactory.

should be cleaned and allowed to stand full of water overnight previous to the day of fumigation. Each barrel will hold a maximum charge of 30 pounds of sodium cyanide, or enough to fumigate about 30,000 cubic feet of space. When it is necessary to fumigate small rooms of a few thousand cubic feet as separate units, earthenware or stone crocks (fig. 13) of appropriate size can be used. Oil barrels sawed in half are used less often.

Each barrel generator should be set in a galvanized-iron washtub in which has been placed a pailful of water containing several handfuls of washing soda. This precaution provides for catching and neutralizing any small quantity of the acid-water mixture that may leak out of the barrel.

If three or four bricks are placed in the bottom of the washtubs

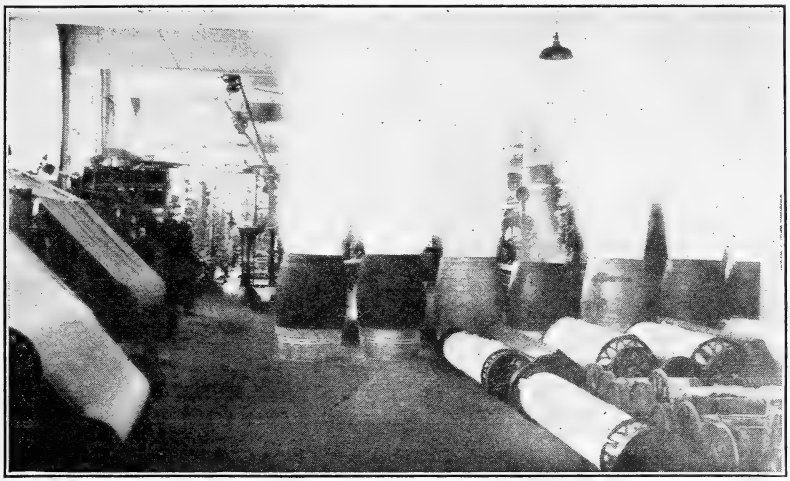

FIGURE 14.—Seven 50-gallon oil barrels, in tubs, arranged in line near the door of a woolen factory. The sodium cyanide has been dropped into the acid-water mixture. Note gas mixed with steam rising from the barrels. Each of these barrels had a charge of 25 pounds of sodium cyanide, the battery of seven barrels generating enough gas for 175,000 cubic feet of mill space.

for the barrels to rest on, the barrels will not become stuck in the tubs. It is much better to have tubs large enough in diameter at the bottom so that the barrels will not come in contact with the sides.

If earthenware crocks are used, these also should be set in small galvanized tubs. It is seldom practical to use crocks of more than 4-gallon capacity. A 3-pound charge of cyanide is the most that can be safely used in a crock of this size without danger of spattering during the evolution of the gas.

Handling Cyanide for the Generator

The weighing of cyanide should be delayed as late as possible before the fumigation is begun. The cyanide absorbs moisture, and if it remains in a paper package for a long time before fumigation, the moisture gathering on the lumps of cyanide will moisten the paper so that when the sack is picked up it may break and discharge the cyanide. Where small charges of cyanide are used,

as in 4-gallon crocks, it is best to use two paper sacks, one of which will fit easily inside the other. By wrapping the unoccupied portion of the sacks tightly about the cyanide and tying with a string, a compact package is obtained, which can easily be lowered into the acid-water mixture with one hand. If two paper bags are used and the cyanide is placed in the inside bag, the action of the chemicals is delayed and the operator is less likely to encounter gas when lowering several charges into the acid containers; however, the danger is still present and operators should wear gas masks and oiled gloves. If the sacks are merely tied close above the cyanide, or twisted, without wrapping, during the reaction the acid-water mixture may be forced up along the neck of the bag and over the edge of the container. If the cyanide is properly packaged, however, there will be no overflow.

When large dosages are used in barrels, sometimes as large as 30 pounds, it is safer to place the cyanide in gunny sacks. When charges in such sacks are lowered into the barrels, gas is evolved at once and the operator must work with dispatch and should wear a mask and oiled gloves. The evolution of gas can be delayed by wrapping the sack in paper and tying the bundle with cord strong enough so that the bundle can be lifted and lowered into the barrel without danger of breakage. A person can then lower several charges before gas is discharged from the first.

Placing the Generators

In the fumigation of large open mills or warehouses, all the generators for one floor can be grouped in a position reasonably close to the exit. It is not necessary to distribute them throughout the room, for the gas is quickly dispersed to all parts of the enclosed space. In fact, where it is impractical to seal off the several floors of a rather small, tight building, excellent results can be obtained in calm weather by placing all the generators on the lower floor. The gas will quickly diffuse throughout the building.

How to Generate the Gas

After the mill or warehouse has been prepared for the fumigation and the generators have been placed in their proper positions, the water and acid are measured out and distributed in the generators. The acid can be poured from the carboys into heavy galvanized-iron buckets, which will resist the action of the acid long enough for it to be distributed without accident. If crocks are used for generators, the acid must be poured into the water slowly with a rotating motion, lest the heat developed by the chemical reaction between the acid and water cause the crocks to break. Crocks should be placed in small metal tubs, containing some water and washing soda, before the acid is poured into the water, so that the acid will not be spilled if the crock should crack. If the crock should crack, the operator must empty it immediately into some handy container provided for such an eventuality.

When the water and acid have been mixed, the sodium cyanide, which has previously been weighed into the proper quantities and wrapped, should be lowered carefully into the generators. If sev-

eral floors are to be fumigated separately, the cyanide should be dropped first into the generators on the top floor, and then on the next lower floor, and so on to the bottom. Starting with the one farthest from the exist (previously determined), proceed from generator to generator calmly and without delay. **Do not retrace steps to a generator accidentally overlooked, as you might encounter higher concentrations of gas than your canister could protect you against.**

If several lines of generators converge at one exit, an operator should be assigned to each line and at a predetermined signal each should start dropping the cyanide in the most distant generator in his line.

Since the gas is generated as soon as the acid-water mixture comes in contact with the sodium cyanide, the operators engaged in dropping the cyanide should wear gas masks, except for very small jobs where only one or two generators are used.

Emptying the Generators

When the fumigation is finished and the building has been thoroughly ventilated, the residue must be emptied from the generators. Sometimes the chemical reaction is incomplete because some of the sodium cyanide has not come in contact with the acid-water mixture or because the wrong proportions of the materials have been used. Therefore, when the generator is moved, the contents are shaken up and additional small quantities of gas may be given off. For this reason the operator should always wear a gas mask while handling the barrels and should not hold his head over the barrel.

The residue, which is poisonous, can be disposed of by dumping it down a street drain or by pouring it into a hole in the ground and covering it with soil.

THE LIQUID METHOD

Liquid hydrocyanic acid is a volatile, colorless liquid, which boils at 79° F. It is marketed in cylinders containing 30 or 75 pounds. On exposure to air it gives off the same gas that is generated by mixing sodium cyanide with sulfuric acid and water. In the hands of an expert fumigator it is an almost ideal fumigant for use in large enclosures.

After a building has been prepared for fumigation, the gas is applied entirely from the outside (figs. 15 and 16). The cylinders containing the liquid hydrocyanic acid are lined up near the building, and the fumigant is forced in by compressed air. A proper distribution of the gas within the building is obtained by means of lines of pressure rubber tubing or metal piping equipped with spray nozzles. A gas mask should be worn at all times by the operator introducing the gas.

PIPING THE BUILDING

In small enclosures the gas can be distributed through rubber tubing, but in large warehouses or mills it is desirable to install a permanent system of piping. This may be constructed of iron, brass, or copper. The iron piping is the least expensive, but, owing to its tendency to rust and cause clogging of the spray nozzles, it is rarely used. Either brass or copper tubing is recommended. A flexible

copper tubing three-eighths inch in diameter (fig. 17) is suitable. Since it can be readily bent, elbow fittings are unnecessary, and compression couplings can be used, except at the main inlet, where the cylinders are connected.

In large buildings, where there are several floors and numerous branch lines must be used, each floor should be provided with a separate riser, which should be of larger tubing. A spray nozzle (fig. 18) should be provided for every 15,000 to 25,000 cubic feet of space. It is customary to use from 10 to 18 nozzles to a riser, but the latter number should not be exceeded.

The piping system should be so arranged that the gas pressure will be approximately the same at all nozzles, thus insuring an even distri-

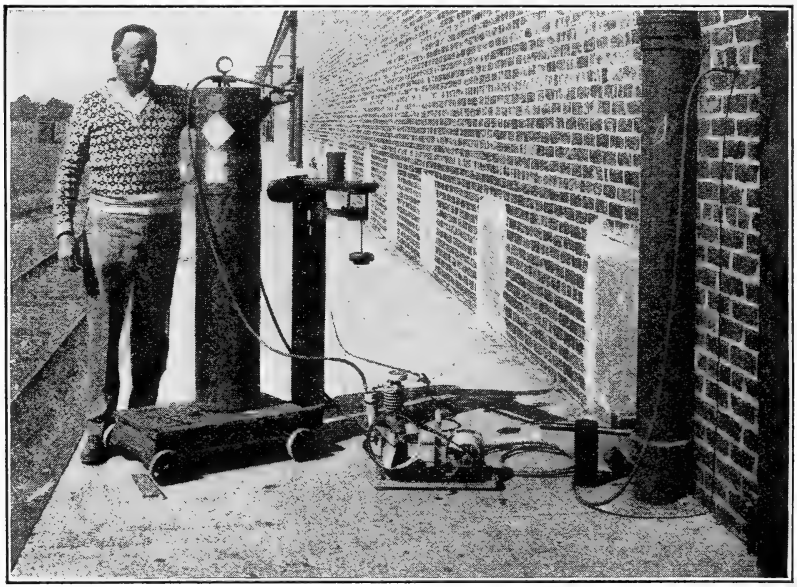

FIGURE 15.—Fumigating a tobacco warehouse with hydrocyanic acid gas, using the liquid method. The liquid hydrocyanic acid in the cylinder on the scales is being forced, by air pressure generated by a small electrically driven compressor, through the rubber tubing from the cylinder to the piping system installed inside but protruding through the walls. **The operator shown should be wearing a gas mask to protect against an accidental breaking of rubber tubing or leakage from valves.**

bution. Each riser is connected to a special inlet pipe leading through the outside wall of the building to the cylinders of gas. Piping plans are usually made by the fumigating company after it has made a survey of the building. Should blueprints or rough sketches and measurements be forwarded for making piping plans, special attention should be given to offsets and whole or part partitions. Any other special conditions, such as heavily infested machinery, rows of packing machines, or other places of heavy infestation, should be noted in order that an extra nozzle may be added if it is thought desirable.

APPLYING THE GAS

Each cylinder of liquid hydrocyanic acid is supplied with an inlet valve and an outlet valve. The outlet valve is attached to a steel tube

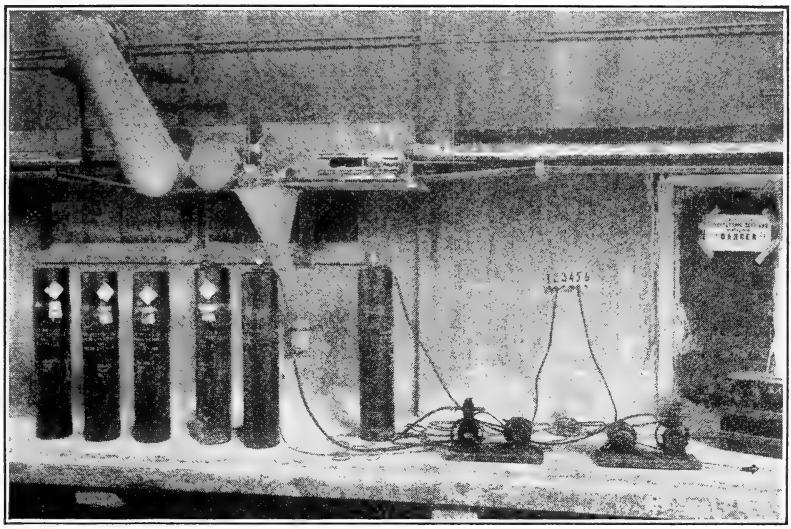

FIGURE 16.—Equipment for fumigation of flour mill from loading platform. Note six cylinders of liquid hydrocyanic acid, two electric motors, outlets in the wall leading to six piping systems to carry fumigant to six separate compartments, floors, or pipe lines within. The two motors are forcing, by air pressure, the liquid hydrocyanic acid in two of the cylinders through rubber hose into two of the systems of copper piping within. Note placard on door warning of danger.

FIGURE 17.—Installation of ⅜-inch copper piping for introduction of liquid hydrocyanic acid. This piping, being flexible and easily cut with a saw, as indicated, can be run along side walls and out along rafters, or to any point where it seems best to install the spray nozzles.

connected with the bottom of the cylinder. The inlet valve leads directly into the top of the cylinder. A check valve should be installed between the inlet valve and the compressor (figs. 15 and 16) to prevent the gas from being forced back into the tubing leading to the compressor, in case of trouble. The outlet valve, which has previously been connected with the inlet pipe to the building, is then opened and the gas is forced in. The pressure must be maintained until the liquid

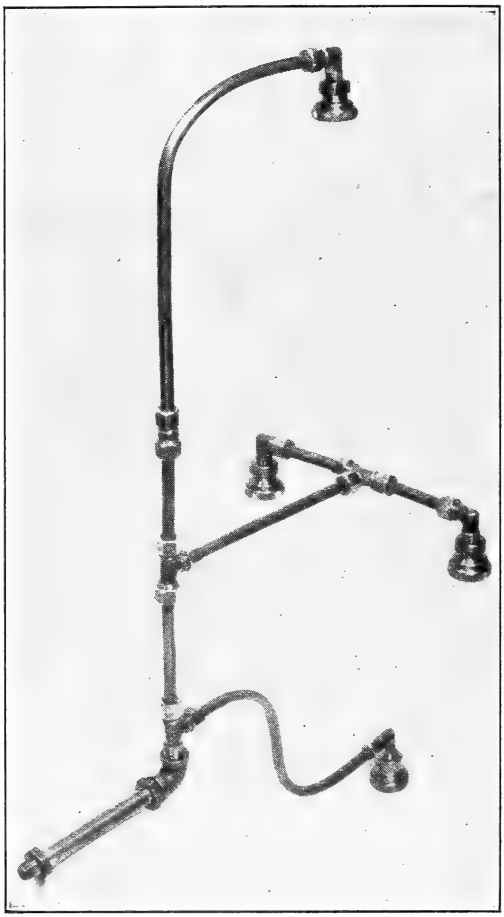

FIGURE 18.—Various attachments for spray nozzles used in fumigating a warehouse, mill, or factory with liquid hydrocyanic acid.

is blown through the pipes into the space to be fumigated. As soon as the required quantity of liquid hydrocyanic acid has been forced into the building, the pipe lines are blown clear and the inlet tubes capped. The time needed to pump the contents of a 75-pound cylinder into a building is approximately 7 minutes.

SAFETY PRECAUTIONS

At the conclusion of the fumigation and after the building has been well ventilated, the spray nozzles should be removed and cleaned for

storage and the pipes capped. In removing these nozzles, care must be taken to avoid accidents from the small quantities of liquid hydrocyanic acid that sometimes remain in the pipes after a fumigation. **The operator should never stand directly in front of or beneath a spray nozzle that is being removed.**

It is best to use a gas mask in this work. The presence of liquid hydrocyanic acid behind a nozzle that is being unscrewed is usually revealed by a well-defined cooling sensation and sometimes by a slight odor. Special pressure nozzles are now on the market which close

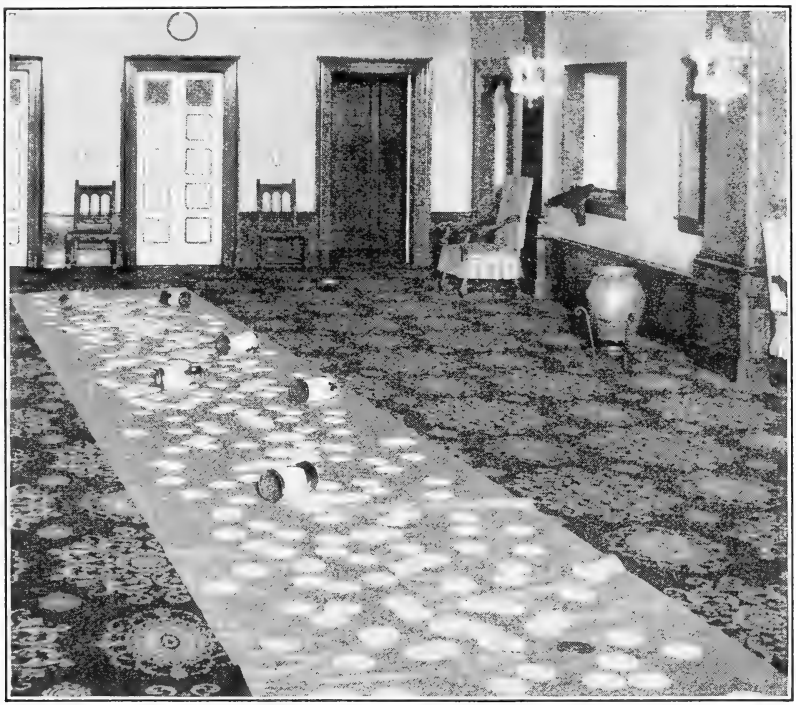

FIGURE 19.—Lobby of apartment house being fumigated with hydrocyanic acid gas generated by the discoid method, showing round white wafers distributed over the paper runner and the empty cans from which they have been shaken. These wafers are wet when distributed, but after the evolution of the gas they become dry and harmless.

automatically when the pressure is removed; hence they do not clog and need not be removed.

In fumigating with liquid hydrocyanic acid, there is always some danger that the rubber connecting hose may burst under the pressure, showering the operator with the deadly fluid. It is therefore a wise precaution to check the rubber hose and all connections thoroughly before turning on the gas and to wear a gas mask while manipulating the valves of the cylinder.

THE DISCOID METHOD

For the fumigation of warehouses that are divided into sections, of mills containing machinery that cannot be easily opened up, or of

apartment buildings, etc., the use of some form of solid from which hydrocyanic acid gas can be produced is often desirable, since it does away with the necessity for an elaborate piping system or for crock or barrel generators.

There are two types of such solids now on the market. One of these consists of liquid hydrocyanic acid absorbed in some inert material from which it evaporates on exposure to air. This inert material is pressed into waferlike discoids each containing approximately one-half ounce of liquid hydrocyanic acid (fig. 19). These discoids are marketed in tightly sealed cans of various sizes and sold on the basis of the net content of hydrocyanic acid. The other type of solid is calcium cyanide, and the hydrocyanic acid is produced by chemical reaction with the moisture in the air. Its use will be discussed under the powder method.

APPLYING THE DISCOIDS

When large quantities of discoids are used, especially in hot weather, it is advisable to chill the cans before fumigating. This will greatly retard the generation of the gas and thus increase the safety of operation. If solid carbon dioxide is available, a liberal quantity thrown over the tops of the cans in each opened case a few hours before fumigating will chill the discoids. Placing cans of discoids in cold storage will have the same effect.

The proper number of cans of discoids should be placed on each floor to be fumigated, and the distribution of the fumigant should be started on the top floor, always from a predetermined point and approaching the exit. The cans are opened with a specially devised can opener that makes a clean cut close to the rim (fig. 20). If several operators are engaged in the work, one can open the cans while the others scatter the discoids over the floor or among the machinery. The men should take turns opening the cans, so that one man will not be exposed too long to the heavy concentrations near the newly opened cans.

Discoids should not be placed directly on painted or varnished floors or woodwork, for the liquid hydrocyanic acid is likely to injure the finish. Two or three thicknesses of newspaper or wrapping paper will provide adequate protection against any liquid that may ooze from the discoids.

When discoids are used, the fumigators are exposed to the gas while they are opening the cans and distributing the contents. **Good gas masks are necessary and will prevent them from breathing poisonous fumes, but there is also some danger from the direct absorption of hydrocyanic acid gas through the skin and of encountering concentrations of the gas above the capacity of the mask.** Williams [4] has estimated that a man protected by a good gas mask can remain in air containing 2 ounces of hydrocyanic acid gas per 1,000 cubic feet for half an hour without being affected; in a concentration of 4 ounces per 1,000 cubic feet this time should be reduced to 15 minutes, and in one of 8 ounces to 5 minutes. The same author calculates that, in distributing discoids at the rate of 8 ounces of hydrocyanic acid per 1,000 cubic feet, a fumigator will be actually exposed for the greater part of the time to from 1 to 2 ounces per

[4] WILLIAMS, C. L. FUMIGANTS. Pub. Health Repts. [U. S.] 46 : 1018. 1931.

1,000 cubic feet. Allowance is made for the fact that the fumigator is constantly moving away from the discoids and that the full quantity of the gas is not given off immediately. If the discoids are chilled before being used, the concentration to which the fumigator is exposed will be less.

From the foregoing data it is evident that, where large quantities of discoids are used, the fumigating crew must be large enough so that the distribution of the fumigant will be speedy and no one man

FIGURE 20.—Man, protected by gas mask, removing the top from a tin can containing discoids impregnated with liquid hydrocyanic acid.

is exposed to the gas for a dangerously long period. **The use of this material is not recommended for any but professional fumigators.**

DISPOSING OF SPENT DISCOIDS

When the fumigation is finished and the building has been well ventilated, the spent discoids and the empty cans can be gathered up and thrown away. At the end of a 24-hour fumigation the discoids will retain not more than a trace of hydrocyanic acid.

THE POWDER METHOD

Calcium cyanide in dust form is used in much the same way as the discoids. On exposure to the air the powder absorbs moisture and a

chemical reaction takes place by which hydrocyanic acid gas is given off.

APPLYING THE POWDER

The required number of cans of calcium cyanide are distributed throughout the building. They are then opened and the contents scattered over the floor in a layer not more than half an inch thick. To facilitate removal of the dust after the fumigation, it may be scattered on strips of paper previously laid on the floor, although it is sometimes placed directly upon the floor (fig. 21). Each can of fumigant is equipped with a special perforated top, which the fumigator puts in place of the friction top when he is ready to use it.

Inasmuch as the gas is given off very rapidly after the dust is exposed to the air, the fumigator should wear a gas mask while dis-

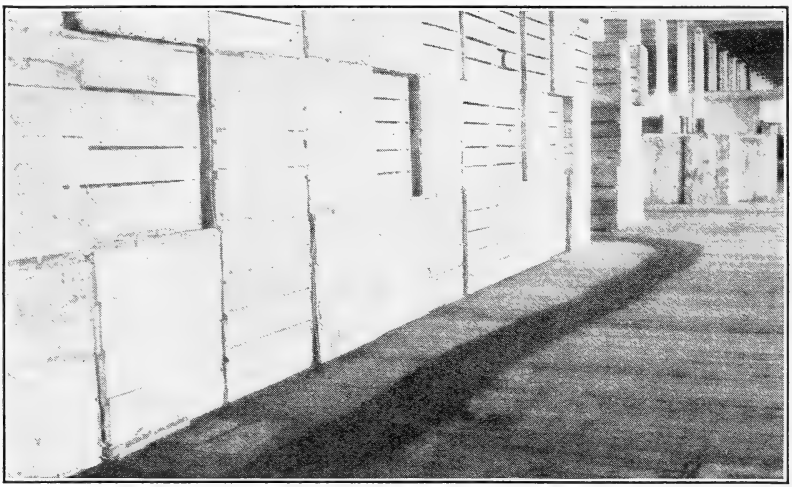

FIGURE 21.—Warehouse being fumigated with hydrocyanic acid gas by the powder method. Calcium cyanide in dust form is spread on the floor, usually from tin cans with perforated covers.

tributing it. As in the case of the discoids, he should begin distributing the dust at the point farthest from the exit, so that he will be working away from the gas that is being given off.

After the fumigation, the paper on which the dust is spread can be rolled up and thrown away, or the dust can be swept from the floor and placed in containers, to be disposed of immediately. The residue, which is mostly calcium hydroxide, is likely to absorb some of the hydrocyanic acid from the air; hence it is advisable to dispose of it outside the building, where small quantities of escaping hydrocyanic acid gas will harm no one. After all the hydrocyanic acid has been given off, the residue is nonpoisonous.

As the dust may be blown about while the building is being ventilated, it should be removed as soon as possible. To obviate this difficulty, as well as for other reasons, the gas is sometimes liberated in a special apparatus (fig. 38). Air is forced by a small motor into a rubberized sack containing the calcium cyanide dust, which is kept

agitated until all the hydrocyanic acid gas is liberated. The gas enters the space to be fumigated through a filtering device, which frees it of the dust.

THE DOSAGE

To figure the quantity of calcium cyanide needed for a fumigation, it is necessary to know the percentage of available hydrocyanic acid it contains. This percentage will be found on the label of the can. If, for example, the dust contains 50 percent of available hydrocyanic acid, 1 pound will give off as much gas as 8 ounces of liquid hydrocyanic acid or 1 pound of sodium cyanide.

Fumigation With Chloropicrin

Chloropicrin, although not so popular as hydrocyanic acid, is sometimes used as a general fumigant for mills and warehouses. It is a colorless or slightly yellowish liquid, a little more than one and a half times as heavy as water. It has a boiling point of 233.6° F., and on exposure to air evaporates slowly, forming a mixture of air and chloropicrin vapor that is 1.1458 times as heavy as air at the same temperature and pressure (77° F., 29.9 inches). It can be purchased in cylinders of from 1 to 100 pounds' capacity, or in glass bottles containing 1 pound. The gas is nonexplosive and noninflammable as ordinarily used, is very toxic to insects and also to man, and has an extremely irritating effect upon the eyes and respiratory passages of man. The last characteristic insures against the possibility of anyone accidentally entering a building filled with gas. **A gas mask equipped with a canister especially designed for the purpose must be worn when fumigating with chloropicrin.**

There are several methods of applying chloropicrin as a general mill or warehouse fumigant. It should not be applied directly on painted or varnished surfaces. Where there are several stories to a building, each floor should be sealed off from the others.

Owing to the rather high boiling point of chloropicrin and consequent slow rate of evaporation, it is sometimes desirable to hasten the process by applying the liquid in the form of a spray or fine mist, or by using a mixture of equal parts of chloropicrin and carbon tetrachloride or trichloroethylene. At temperatures above 70° F., however, satisfactory results can be obtained by merely applying the straight chloropicrin.

In mills that are equipped with machinery for handling foodstuffs, it is desirable to apply the chloropicrin directly into the machinery where the heaviest infestation is likely to be found.

One-pound "automatic" cylinders of chloropicrin charged with carbon dioxide are sometimes used for treating machinery. They are supplied with a short length of hose ending with a spray nozzle. The nozzles are inserted into holes bored into the machinery, and the gas is released by opening a valve on the cylinder. The pressure of the carbon dioxide expels the chloropicrin in a fine mist.

An objectionable feature of chloropicrin is that considerable time is required to ventilate a building after a fumigation. Because it does not evaporate rapidly, it clings to fumigated commodities with great tenacity.

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Fumigation With Ethylene Oxide-Carbon Dioxide Mixture

Warehouses and storage rooms that are of modern tight construction can be successfully fumigated with a mixture of ethylene oxide and carbon dioxide. This mixture is put up in cylinders in the proportion of 1 part by weight of ethylene oxide to 9 parts of carbon dioxide. It leaves no obnoxious odor or poisonous residue on the commodity fumigated. The mixture is sold in 30- and 60-pound cylinders. It is noninflammable and not highly toxic to human beings, but high concentrations have an anesthetizing effect. Concentrations of more than 10 percent with carbon dioxide must also be avoided.

The application of the ethylene oxide-carbon dioxide mixture is exceedingly simple. The requisite number of cylinders are placed

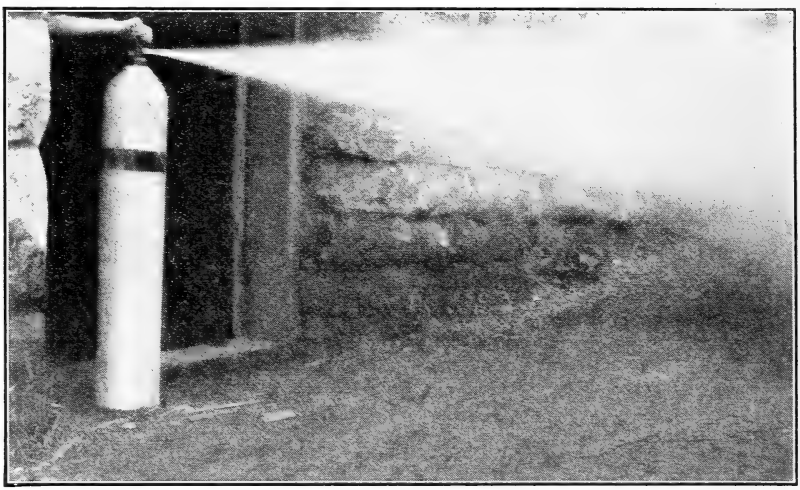

Figure 22.—Cylinder of ethylene oxide-carbon dioxide mixture being emptied automatically by the pressure of carbon dioxide within.

in the room to be fumigated and the valves opened. The pressure of the carbon dioxide automatically discharges the contents of the cylinders in the form of a very fine mist, which vaporizes at once (fig. 22). A cylinder of the mixture will empty itself in about 5 minutes after the valve has been opened wide.

When the valves are opened wide, the force of the escaping gas often causes the cylinders to topple over. To avoid this, the cylinders can be lashed to the walls of any stationary object, or several cylinders can be lashed together with the discharge vents pointing in opposite directions.

Unless a large number of cylinders are used in a fumigation, the valves can be opened without the use of a gas mask, although it is not advisable to stay in a strong concentration of the gas for any appreciable length of time. Before starting the fumigation it is well to see if the valves on all the cylinders can be opened easily by hand; any that are stuck should be loosened with a wrench.

If desirable, a storage room can be piped in the same manner as for liquid hydrocyanic acid, and the ethylene oxide-carbon dioxide

released into the room from the outside. The cylinders are all equipped with fittings that can be connected with the piping system (fig. 23).

The minimum quantity of this mixture that should be drawn from a cylinder at one time is 10 pounds, since it is difficult to withdraw uniform mixtures of carbon dioxide and other fumigants in smaller quantities. When portions of cylinders of mixed gases are used, it it well to follow the instructions of the manufacturers.

Where the floors are painted or varnished, the cylinders should be placed in shallow pans or on several thicknesses of newspaper, to

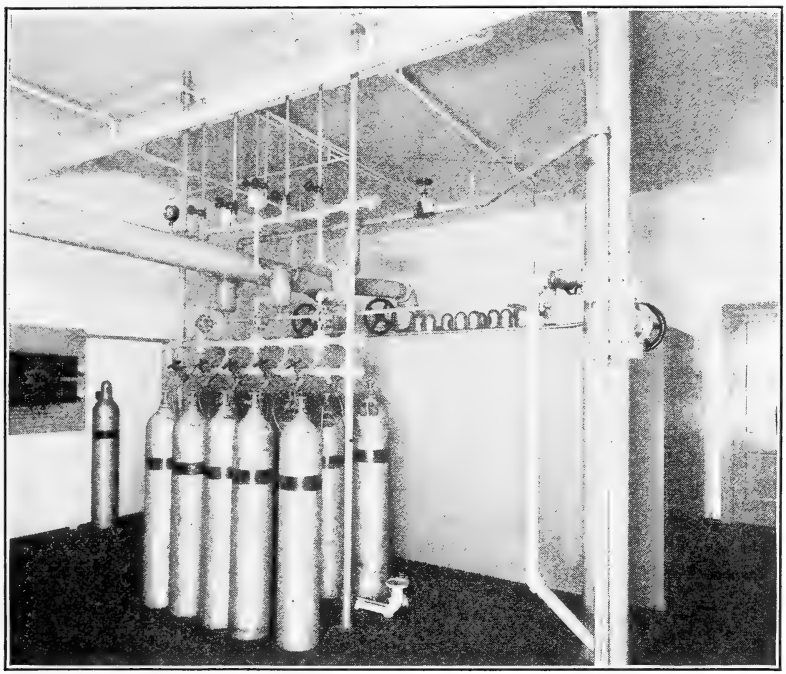

FIGURE 23.—Battery of 10 cylinders of ethylene oxide-carbon dioxide mixture attached to manifold, heaters, and distributing pipes connecting with storage vaults (not shown) in room. In lower background is a 6- by 8- by 10-foot metal fumigation vault, which opens into the room beyond.

prevent damage in case the liquid should run down the side of the cylinder.

This mixture is very effective in rooms that are nearly airtight, but it should not be used in rooms that are loosely constructed. After the fumigation and ventilation all that is necessary is to roll the empty cylinders out of the room and return them to the owner.

FUMIGATION WITH METHYL BROMIDE

Methyl bromide, one of the newer fumigants, is proving to be exceedingly useful in certain types of fumigation work. It is a colorless liquid which boils at 40.1° F. At room temperatures it is a gas weighing 0.247 pound per cubic foot. It is obtainable commercially in liquid form in 1-pound cans or in cylinders containing 10, 50, or 150

pounds net. The natural pressure of the gas is sufficient at room temperature so that both cans and cylinders are self-emptying when opened. However, the pressure in the cylinders is increased slightly by the manufacturers to facilitate the rapid removal of the gas.

Methyl bromide is relatively cheap, highly toxic to all stages of insects including their eggs, noninflammable at concentrations used in commercial practice, and can be used successfully at comparatively low temperatures. It has remarkable powers of penetration and is undoubtedly the most efficient fumigant known for the treatment of warehouses filled with bagged commodities. It is useful, however, only in buildings of modern concrete or brick construction. As it does not kill quickly, it is useless in loosely constructed buildings, where leakage is high. Lacking a distinctive odor, this gas is but faintly noticeable in small amounts, a feature that creates a hazard that is not present with some of the rapidly toxic gases that possess distinctive warning properties.

As a general fumigant for mills or warehouses of modern tight construction methyl bromide can be applied through a piping system in much the same manner as described for liquid hydrocyanic acid. Each cylinder of methyl bromide is equipped with a siphon tube so that it can be emptied without inverting the cylinder. Preparatory to liberation of the gas the pressure in the cylinder is usually increased with compressed air to 150 pounds. The cylinder is then connected by the single outlet to the manifold of the piping system of the mill or warehouse being fumigated, and the valve is opened. The pressure forces the fumigant from the cylinder into the fumigation line at the rate of about 10 pounds per minute. In cool weather the pressure in the cylinder must sometimes be built up with compressed air a second time to speed up the emptying of the cylinder and the application of the gas. A three-way connection between the cylinder, the manifold, and the air compressor will facilitate this operation.

Small warehouses that do not have a piping system can be fumigated by distributing the requisite number of cylinders uniformly over the warehouse floor and releasing the gas by opening the valves. Since the gas is heavier than air, the valve opening of each cylinder should be connected to ⅜-inch copper tubing of sufficient length to reach nearly to the ceiling. By plugging or pinching shut the exit openings of the copper tubes and boring holes through the tubes near the ends, a better distribution of the fumigant will be obtained.

Exposure periods are similar to those used for hydrocyanic acid fumigation, and the same precautions should be taken in applying the fumigant as well as in ventilating the fumigated buildings. In referring to the human hazard connected with the use of methyl bromide for fumigation, the United States Public Health Service [5] states that, **"while methyl bromide is less toxic to man than certain fumigants, all persons fumigating with methyl bromide or mixtures containing methyl bromide, or persons entering fumigated rooms, cars, or sheds to open ventilators or to unload fumigated materials, observe precautions used with other toxic fumigating gases. Experience indicates that adequate precaution will obviate danger of injury by this gas."**

[5] PRELIMINARY RECOMMENDATIONS TO FUMIGATORS USING METHYL BROMIDE OR MIXTURES CONTAINING METHYL BROMIDE AS A FUMIGANT. U. S. Pub. Health Serv., Natl. Inst. Health, Division of Industrial Hygiene, Mimeographed Leaflet, May 16, 1938.

Methyl bromide is not recommended for the fumigation of foodstuffs that have a high fat content or for milled cereals intended for human consumption, since these products retain quantities of residual bromides that may be harmful. Unless otherwise noted, a common dosage is 1 pound to each 1,000 cubic feet of space.

Fumigation With Methyl Bromide-Carbon Dioxide Mixtures

A mixture of methyl bromide and carbon dioxide is available as a fumigant for use in vacuum chambers, atmospheric vaults, and tight storage rooms. It is sold in steel pressure cylinders containing 50 pounds. The dosages recommended vary with the commodity to be fumigated, but under ordinary atmospheric conditions the usual dosage is 15 to 20 pounds of the mixture per 1,000 cubic feet for an exposure of 24 hours. The fumigant is discharged into the atmospheric fumigation chamber or storage room in the form of a slush or snow, or as a gas. It is more quickly effective if it is first passed through a vaporizer and introduced as a gas, as is the practice in vacuum fumigation.

Fumigation With Methyl Formate-Carbon Dioxide Mixtures

Warehouses and storage rooms that are thoroughly modern in construction can be fumigated with mixtures of methyl formate and carbon dioxide. Ordinarily these mixtures are used only in special fumigation vaults. The value of methyl formate as a fumigant was first established by the experimental work of this Department. Alone, its vapors are explosive and inflammable in the presence of fire in any form; hence, mixtures with carbon dioxide have been developed, the vapors of which are entirely free from the fire and explosion hazard.

The methyl formate-carbon dioxide mixtures can be obtained in steel pressure cylinders containing a net weight of 5, 8, 25, 50, or 60 pounds. When used in connection with vault fumigation, the cylinder is set on platform scales close to the vault wall, through which the desired dosage is discharged. The method of application is the same as that recommended for the methyl bromide-carbon dioxide mixture.

The vapors seem to be harmless to food and other commodities thus far treated, and they are only slightly toxic to man as he ordinarily comes in contact with them in fumigation work. The recommended dosage is 28 pounds per 1,000 cubic feet of empty space, with an exposure of from 12 to 24 hours. Several mixtures have been offered to the public, but one containing about 15 percent of the methyl formate seems to be the most effective and safe. This fumigating mixture is similar to the ethylene oxide-carbon dioxide mixture in the manner in which it is marketed and used.

VAULT FUMIGATION

Many establishments have use for a small fumigation vault for the treatment of incoming raw materials, returned goods, outgoing products, etc. Such a vault may be constructed of any material that can be made gastight or reasonably so.

Several types of metal vaults (fig. 24) can be purchased knocked down ready for assembling. These are excellent in every way. Highly satisfactory vaults can be constructed of concrete, brick, or

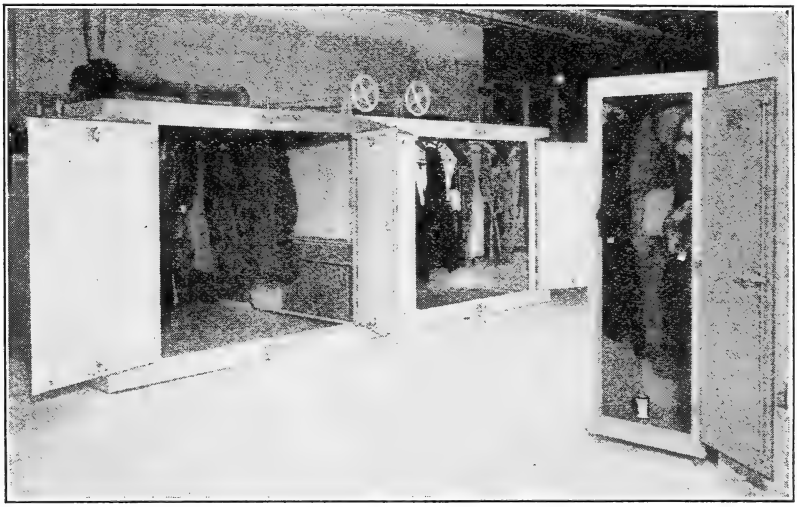

FIGURE 24.—Two types of metal vaults such as can be purchased or built according to space and commodity need. These vaults are used for treating the day's arrival of fur coats offered for summer storage. After an overnight fumigation in these vaults the furs are removed to large permanent storage vaults.

FIGURE 25.—Two outdoor fumigation vaults under one roof, built of brick, finished on the inside with Keen's cement, and equipped with doors shutting against rubber gaskets to prevent gas leakage. Note ventilators in roof to aid in ventilation when lighter-than-air gas is used. (Photograph by Perez Simmons.)

hollow tile. The brick (fig. 25) and hollow-tile (fig. 26) vaults should be finished inside with a layer of Keen's cement and one or two coats of paint. Wooden vaults with a metal lining are also

popular. It is possible to purchase 14-gage sheet metal cut up into sections for constructing a vault 8 by 10 by 12 feet. When welded together, the sections form an excellent gastight lining.

The cheapest type of vault is made of wood. A useful vault can be constructed of two layers of 1-inch standard flooring separated by a layer of heavy roofing paper. If the edges of each board are painted with heavy white lead paint just before the tongue and groove are forced tightly together, the walls are even tighter. The floor, walls, and roof should be of the same tight construction. The interior should be given two or three coats of any good paint. An aluminum paint is sometimes used to advantage.

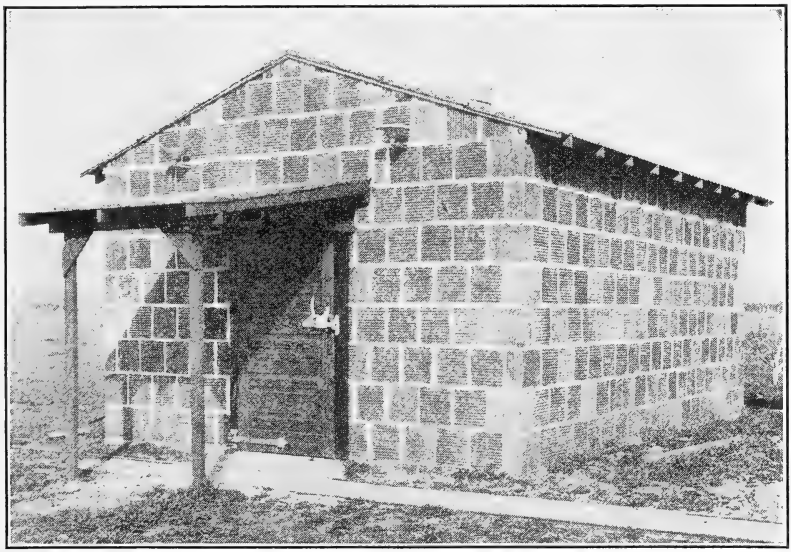

FIGURE 26.—Outdoor structure built for fumigation of dried fruits. It is made of hollow tile, plastered on the inside with Keen's cement, and equipped with a refrigerator-type door. Note funnel-shaped openings above the door, through which a liquid fumigant can be poured into evaporating trays suspended from the ceiling of the vault. (Photograph by Perez Simmons.)

All types of vaults should be equipped with a refrigerator or safe type of door, well gasketed to make it gastight.

A ventilating system capable of quickly removing the fumigant from the vault after the fumigation is essential. If the vault is set up inside a building, the ventilating stack must extend outside the building and preferably above the roof.

It is sometimes desirable to install an electrical heating unit, controlled by a thermostat, so that a constant high temperature can be maintained throughout the fumigation. The heating unit should not be operated, however, while inflammable fumigants are being used.

For applying the fumigant several different methods can be used. For heavier-than-air gases a shallow evaporating pan or trough should be installed near the ceiling of the vault, with a feed pipe extending outside (fig. 26). The fumigant can then be run into the evaporating pan by gravity or compressed air. If liquid hydrocyanic acid or any of the commercial mixtures is to be used, a short

piping system with one or more spray nozzles can be installed (figs. 17, 18, and 23).

Use of Fumigants Suitable Also for Large Spaces

Hydrocyanic acid, chloropicrin, methyl bromide, and mixtures of carbon dioxide with ethylene oxide and methyl formate are all suitable for vault fumigation, and they can be used in the manner described for the fumigation of large spaces. The method selected for generating hydrocyanic acid will depend largely upon the preference of the operator. Any of the previously described methods is suitable. If calcium cyanide is used, it can be sprinkled in a thin layer on a strip of paper laid on the floor or on shelves built for the purpose. Chloropicrin can be applied by pouring the dosage into the evaporating pan or by forcing it in through a piping system with compressed air. The mixtures of ethylene oxide and methyl formate with carbon dioxide are applied through a piping system and can be administered by connecting the cylinder to the system (fig. 23) and opening the valve. If the cylinder is placed on a platform scale, it is an easy matter to let in the quantity desired.

Use of Other Fumigants

Various other fumigants, not suitable for warehouse fumigation, can be used successfully for vault fumigation. They are carbon disulfide, ethylene oxide, ethylene dichloride-carbon tetrachloride, and carbon tetrachloride.

CARBON DISULFIDE

Carbon disulfide is a colorless, volatile liquid, which boils at 114.8° F. On exposure to air it evaporates, forming a heavy vapor that is very toxic to insects.

It is applied by pouring the liquid into the evaporating pan of a vault at the rate of about 5 pounds per 1,000 cubic feet of space. If the vault is not tight or if highly absorbent commodities are being treated, the dosage should be increased proportionately. It is not uncommon to use from 20 to 30 pounds per 1,000 cubic feet.

Unfortunately, the value of carbon disulfide as a fumigant is greatly limited owing to the highly inflammable nature of its vapors, which restricts its use to situations where the fire hazard can be effectively controlled. In admixture with air the vapors, which are both inflammable and explosive, may ignite from fire or even without the presence of flame at temperatures of 212° F. or above. Fire insurance is void while carbon disulfide is being used. It should be remembered that lighted lanterns, cigars, pipes, cigarettes, pilot lights in gas stoves and heaters, sparks from electric switches, static or frictional electricity, sparks caused by hammering on metal, and even hot steam pipes may cause an explosion of the vapor. For this reason carbon disulfide should be used only where the fumigation vault is isolated from other buildings and the fire hazard can be controlled.

Mixtures of carbon disulfide with other chemicals, such as carbon tetrachloride and sulfur dioxide, for the purpose of reducing the fire hazard are now on the market. Although not absolutely noninflammable, they can be used with comparative safety. Their efficacy is

directly proportional to the carbon disulfide content, and they should be used accordingly.

The vapors of carbon disulfide are poisonous to human beings if breathed for an extended period. Exposure to light concentrations may induce a feeling of giddiness, which, however, will quickly pass when the person affected comes into the fresh air.

CARBON TETRACHLORIDE

Carbon tetrachloride is a colorless, volatile liquid having a boiling point of 170° F. Its vapors are noninflammable, and therefore it is sometimes recommended as a fumigant in place of carbon disulfide.

It is not very effective when used alone against insects that infest stored products and should be chosen only when no other fumigant will do. Its chief use is for mixing with more toxic fumigants to reduce the fire hazard.

To be at all effective, it must be used at a temperature of 75° F. or higher, and at the rate of at least 30 pounds per 1,000 cubic feet of space. It is applied by pouring it into the evaporating pan of the vault. The vapors of carbon tetrachloride have an anesthetic effect when breathed by man. Although they are not quickly toxic, it is not safe to remain for any length of time in a strong concentration of the gas.

ETHYLENE DICHLORIDE

Ethylene dichloride is a colorless liquid with an odor similar to that of chloroform. It has a boiling point of 183.2° F., and on exposure to air it evaporates. The mixture of air with ethylene dichloride vapor is 1.2552 times as heavy as air at the same temperature and pressure (77° F., 29.9 inches).

It is an effective fumigant in gastight vaults, but owing to its high boiling point it should be used at a temperature of at least 70° F. and preferably somewhat higher.

The vapors of ethylene dichloride are slightly inflammable. It is therefore customary to use this fumigant in combination with some noninflammable chemical, such as carbon tetrachloride or trichloroethylene. A mixture of 3 volumes of ethylene dichloride with 1 volume of carbon tetrachloride or trichloroethylene is free from fire hazard under ordinary conditions, and is an effective fumigant when used at the rate of 14 pounds per 1,000 cubic feet of space, unless the vault is filled with absorbent material, when a heavier dosage is required.

This fumigant is applied by pouring it or forcing it under pressure into the evaporating pan of the vault. A small fan blowing on the surface of the liquid insures a more rapid vaporization of the fumigant and hastens its killing action.

The vapors of ethylene dichloride have an anesthetic effect upon man. **One should not be exposed to a heavy concentration of the gas for more than a very brief period without a gas mask.**

The mixture of ethylene dichloride and carbon tetrachloride or trichloroethylene has no corrosive action on metals or any bleaching or staining action on textiles of any sort. It is suitable for treating grains and seed, but should not be used for foodstuffs with high fat

content, for they are likely to retain a disagreeable odor and taste after fumigation.

Ethylene dichloride can be purchased separately or already mixed with carbon tetrachloride or trichloroethylene.

ETHYLENE OXIDE

Ethylene oxide is a colorless gas at ordinary temperatures, but below 50° F. it is a colorless liquid. It has a boiling point of about 57.2°, and therefore can be used with success at temperatures considerably below 70°.

The concentrated vapor of ethylene oxide is inflammable, but concentrations up to 3½ pounds per 1,000 cubic feet of space are nonexplosive and noninflammable.

A dosage of 2 pounds per 1,000 cubic feet will give satisfactory results in a tight vault, with an exposure of from 10 to 20 hours. The liquid, which is sold in cylinders, can be drawn off into a measuring container and poured into the evaporating pan of the vault. Owing to its extreme volatility, it should not be drawn from the cylinder until the fumigation chamber is ready for the charge.

Ethylene oxide gas is not injurious to fumigated commodities, and no obnoxious odor or poisonous residue is left upon them. The gas is not highly toxic to man. **Nevertheless, the operator should avoid breathing the fumes for any length of time and should not enter a heavy concentration without wearing a gas mask.**

If ethylene oxide is used alone, it is advisable not to operate an electric fan inside the vault, lest an inflammable concentration of the gas has been accidentally obtained.

Ethylene oxide can be purchased in cylinders containing 3½, 18½, 75, or 195 pounds.

BIN FUMIGATION

Bins used for the storage of foodstuffs, yarn, hosiery, etc., frequently need to be fumigated. For this purpose any of the heavier-than-air gases, such as carbon disulfide, chloropicrin, ethylene oxide, or ethylene dichloride-carbon tetrachloride mixture, can be used, provided it is suitable for treating the commodity stored in the bin. Carbon disulfide should not be used unless the fire hazard can be controlled.

The fumigant should be sprinkled or sprayed evenly over the surface of the contents of the bin, and the bin should then be covered as tightly as possible. As the fumigant evaporates, the vapor, being heavier than air, gradually penetrates the material from the top to the bottom.

The quantity of fumigant needed will depend upon the tightness of construction of the bin, the type of material to be fumigated, and the fumigant being used. Bins are seldom so tight as fumigation vaults; hence larger dosages are necessary.

Since it is difficult to obtain uniform penetration of fumigants beyond certain depths in bins, it is often desirable to apply the fumigant in separate portions as the bins are filled.

VACUUM FUMIGATION

In vacuum fumigation commodities are placed in a gastight steel chamber, and a large portion of the air is removed and replaced with a gas lethal to insects. By this method immediate penetration of commodities by the gas is obtained and the susceptibility of the insects is increased by the reduction of the oxygen content of the chamber. This permits smaller dosages and shorter exposures than under atmospheric conditions. With many commodities the period of exposure may be reduced to as short a time as 1 hour, a feature that has an appeal in industries where speed is essential, as in the handling of foodstuffs and similar commodities.

In addition to reducing the dosage and length of exposure, this method of fumigation offers further advantages. At the end of a fumigation the removal of the fumigant can be speeded by the process known as air washing, which consists in drawing a high vacuum and breaking it with air. Furthermore, workmen are not exposed to such heavy concentrations of gas while unloading a fumigation chamber.

Equipment

Vacuum chambers are either cylindrical (figs. 27, 28, and 29) or rectangular (fig. 30). They are made in all sizes, from laboratory outfits with a capacity of about 1 cubic foot up to those capable of holding one or more carload lots. The size of the chamber will depend on the type and quantity of material to be fumigated and the space available for it in the factory. Some firms prefer to have two chambers that can be operated with one set of equipment. While one chamber is under fumigation, the other can be loaded or unloaded and the fumigation crew kept continuously busy.

The tanks are usually installed so that small trucks or factory skids can be run into them. If the vacuum chamber is equipped with a door at each end, the trucks can be run in at one end and out the other, so that the fumigated products will not interfere with the next load. In some factories one end of the chamber opens into the receiving room and the other end into the general storage room. Raw materials likely to be infested are then fumigated before they are placed in the general storage rooms.

The doors of the vacuum tank should be so balanced and hung that they can be quickly opened and closed by one man. The gaskets should be durable and at the same time provide a gastight seal. The efficiency of a tank depends largely on its freedom from leaks. A well-built tank should hold a vacuum without perceptible loss throughout the average fumigation period.

Each installation requires a vacuum pump capable of drawing a 28-inch vacuum in 10 minutes or less.

Recent work has demonstrated that it is advantageous to introduce the fumigant into all parts of the tank at once instead of through one inlet. Rectangular tanks are now being supplied with multiple gas inlets spaced evenly along the four longitudinal sides.

It has also been demonstrated that by circulating the gas in a tank the dosage can be reduced 25 percent by virtue of the better distribu-

FIGURE 27.—A two-tank vacuum fumigation plant installed in a large tobacco establishment in North Carolina. Each tank is 63 feet long by 8 feet in diameter and takes a load of 43,000 pounds of Turkish tobacco per fumigation. Note doors at right swinging away from ends of tubes, the powerful vacuum pump, the automatic devices for recording vacuum and temperature, and the cylindrical accumulator on top of tank. Attachments for introducing the fumigant are on the opposite side.

tion obtained. By means of a bypass from the exhaust to the multiple gas-inlet system the vacuum pump can be utilized to circulate the gas in the tank. This feature is now standard equipment with some tanks.

The use of a vaporizer in connection with a vacuum chamber increases its efficiency by insuring the entrance of the fumigant in a gaseous state. The most common type of vaporizer consists of a steel tank in which steam is generated by means of electric heating elements. A copper coil, through which the fumigant is conducted, runs through this steam-heated tank and is so designed that the fumigant is in gaseous form by the time it reaches the vacuum chamber. If carbon

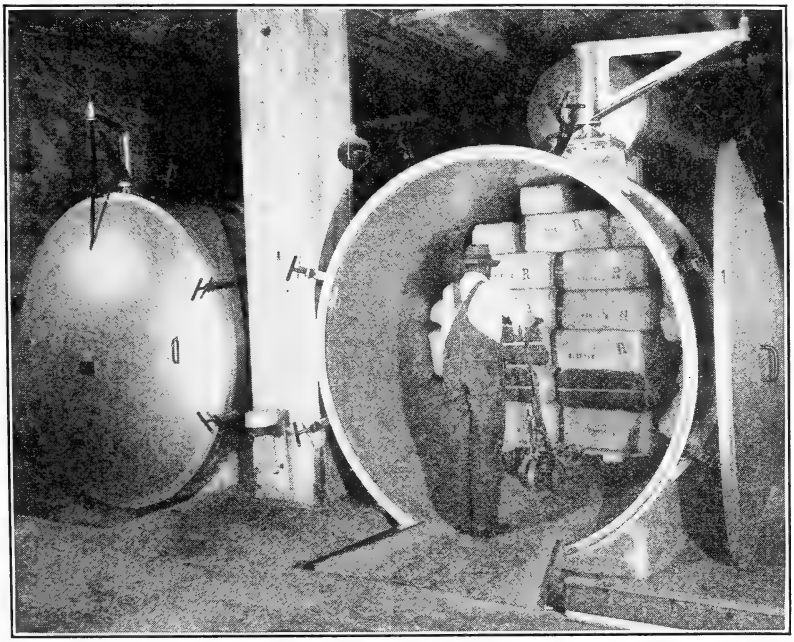

FIGURE 28.—End view of vacuum equipment shown in figure 27. Tank at left closed and under fumigation. Tank at right nearly loaded with 43,000 pounds of Turkish tobacco. These tanks will treat all incoming tobacco placed in this storage establishment. Note end of cylindrical accumulator on top of tank at right.

disulfide is used, a specially designed vaporizer is required, since it must be mixed with carbon dioxide before it is admitted to the fumigating chamber.

In some vacuum outfits an accumulator tank (fig. 27) is utilized to vaporize and heat the fumigant before drawing it into the vacuum chamber. It consists of a tank with a heating coil into which the dosage is drawn, and in which it can be held until ready for use.

Hydrocyanic acid, chloropicrin, methyl bromide, and mixtures of carbon dioxide with ethylene oxide, methyl formate, and carbon disulfide are used in vacuum fumigation. The dosage required depends on the type and quantity of the commodity to be fumigated, its temperature, and the length of exposure.

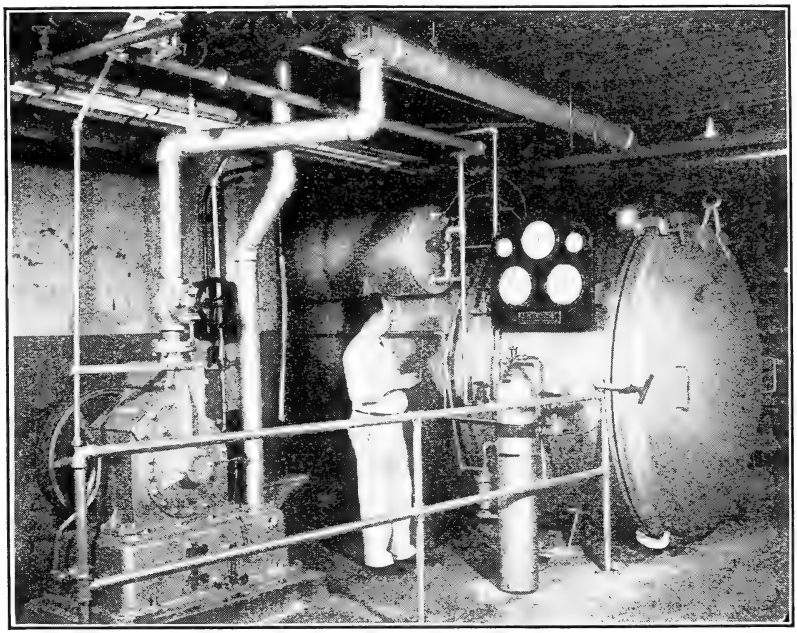

FIGURE 29.—Portion of vacuum fumigator installed in a large candy establishment. Note vacuum pump in left foreground; cylindrical accumulator on tank; gages for automatically recording pressure, vacuum, and temperature; and cylinder of the ethylene oxide-carbon dioxide mixture in front of operator. Cylinders of methyl formate-carbon dioxide and methyl bromide-carbon dioxide mixtures are attached in the same manner.

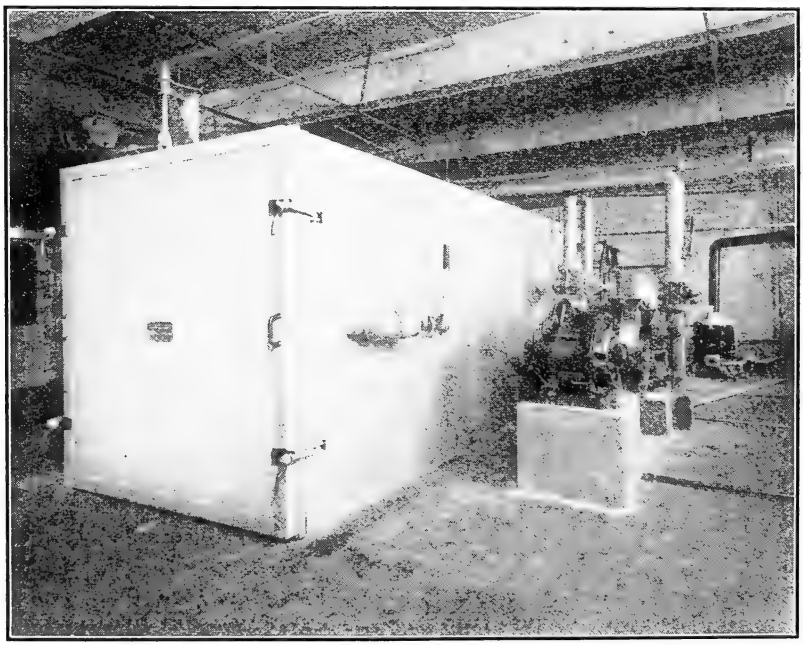

FIGURE 30.—New type of rectangular fumigation chamber. Note vacuum pump at right, with temperature and vacuum gages and other equipment behind it.

Procedure

The commodity to be fumigated is loaded into the vacuum tank, the doors are closed, and air is removed until the vacuum gage registers 28 or 29 inches. The proper dosage of fumigant is then admitted through the vaporizer or accumulator.

If the tank is equipped with multiple gas inlets and a gas-circulating system, the fumigant should be pumped from the accumulator tank into the vacuum tank through the circulating system. When all the fumigant is in the tank, the valve to the accumulator tank should be closed and the necessary valve adjustments made to allow the gas to be circulated in the vacuum tank. The gas should be circulated for 15 minutes. By holding the remaining vacuum without change for the duration of the fumigation, better results are obtained than by breaking the vacuum with air. If the instrument panel is equipped with a recording device, a chart record (fig. 31) can be made of each fumigation for future reference.

The dosage is usually measured by weighing the fumigant into the tank or vaporizer, by measuring it volumetrically, or by dropping the vacuum a given number of inches with the fumigant. The first two methods are accurate. The third method cannot be used indiscriminately, since with a given quantity of gas the drop in vacuum will vary both with the quantity and the type of commodity being fumigated and with the temperature of the gas and of the commodity in the tank. It is convenient for commercial fumigations, however, and if proper allowance is made for these variations it will be sufficiently accurate for ordinary work.

At the end of the fumigation the gas is pumped out of the tank and the vacuum is broken with air. If desired, the fumigated products can be "air-washed" several times by alternately drawing and breaking a vacuum of about 27 inches.

When large tanks filled with commodities of an absorbent nature are being unloaded, the residual gas is quite noticeable. **Workmen should be equipped with gas masks having canisters designed to protect against the gas being used before they are permitted to unload the tank.** It is a wise policy to keep the pump in operation during the unloading process so that a stream of fresh air will be drawn constantly through the tank, thus reducing the concentration to which the workmen are exposed.

The temperature of the commodity is an extremely important factor in vacuum fumigation. Cold commodities, particularly highly absorbent materials such as flour products, cannot be treated successfully unless large dosages are used. A temperature of 70° F. or above is desirable. If possible, commodities taken from cold storage should be allowed to come to room temperature before being treated.

FUMIGATION OF VARIOUS COMMODITIES

Since it is impossible to discuss here in detail the fumigation of all the many types of commodities that become infested with insects, only those commodities most often fumigated in commercial establishments are included in this circular. The fumigation of dried beans and grain in bulk on the farm and in the terminal elevator is

discussed in other publications of the Department.[6] No attempt is made to discuss the fumigation of any commodity from a quarantine standpoint. For more detailed information regarding the treatment of any commodity discussed in the following pages, or regarding commodities not mentioned, the reader should direct inquiries to the Bureau of Entomology and Plant Quarantine, United States Department of Agriculture, Washington, D. C.

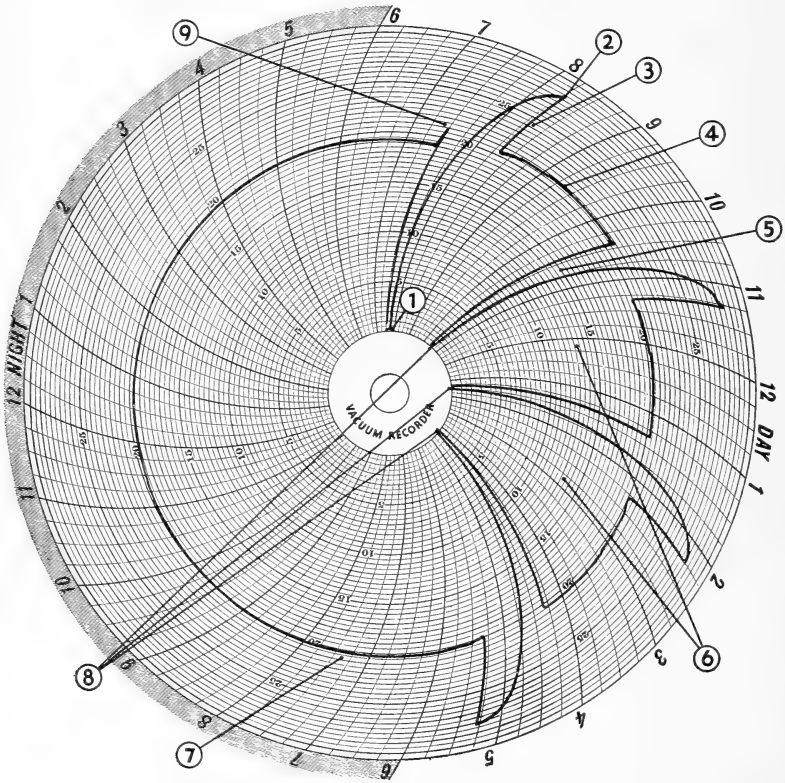

FIGURE 31.—Automatic record of four vacuum fumigations conducted during a period of 24 hours. Hours of day and night are indicated on the circumference of the chart. Figures in circles indicate: (1) Vacuum pump started; (2) chamber exhausted to 28.5 inches of mercury; (3) fumigant (ethylene oxide-carbon dioxide mixture) introduced; (4) treatment period of 2 hours; (5) vacuum pump operating and breaker valve opened simultaneously, providing an air wash of product fumigated; (6) treatment cycles similar to (4); (7) last fumigation of day allowed to continue overnight; (8) doors opened, commodity removed, and a new lot placed in chamber; (9) vacuum pump started before breaker valves were opened, accounting for the rise in vacuum at this point.

CONFECTIONERY

Since the insect problems of the candy and nut-meat industries are rather closely associated, it seems logical to discuss them under one heading. Nut meats are highly susceptible to insect attack, and

[6] U. S. Department of Agriculture Farmers' Bulletin 1260, Stored-Grain Pests; Farmers' Bulletin 1275, Weevils in Beans and Peas; Farmers' Bulletin 1811, Control of Insects Attacking Grain in Farm Storage; and Farmers' Bulletin 1880, Control of Insect Pests of Grain in Elevator Storage.

because they are used in large quantities in the manufacture of candy, they constitute an important source of insect infestation in the candy factory.

Most firms handling nut meats attempt to ship only insect-free nuts. To do this they keep their factories and storage warehouses as free from infestation as possible, in addition to fumigating all outgoing merchandise. A yearly fumigation of the factory with hydrocyanic acid gas, supplemented by constant attention to cleanliness, will reduce insect infestation to a minimum. A dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet is sufficient for this purpose. An exposure of 24 hours is desirable.

Where nut meats in the shell are stored without cold storage, it sometimes becomes necessary to fumigate the warehouses also. Hydrocyanic acid is the best fumigant for this purpose and should be applied at the rate of 16 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet. Excellent results can be obtained in tightly constructed warehouses, even though the bagged nuts are piled in large stacks. If possible, a 48-hour exposure should be given.

Nuts absorb considerable hydrocyanic acid gas, and therefore a warehouse that has been fumigated cannot be aired out very quickly. Large stacks of bagged nuts hold the gas and give it off slowly over a period of several days. In one fumigation conducted by the writers in an exceptionally tight warehouse, bagged peanuts retained so much of the gas that it was unsafe for workmen to enter the warehouse until it had been aired for 5 days. When ventilation is ample, however, workmen can usually enter the following morning, after the gas escaping from the sacked nuts during the night while the warehouse is closed has been blown out of the main aisles.

VAULT FUMIGATION FOR NUTS

Nuts are usually fumigated in atmospheric vaults or vacuum tanks before they leave the factory or go from the storage warehouse to the factory. A 1,000-cubic-foot atmospheric vault will hold about half a carload of bagged nuts, such as peanuts—about two hundred and fifty 100-pound bags of shelled peanuts or 125 such bags of peanuts in the shell.

A dosage of 3 pounds of ethylene oxide or 25 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet of space, with an exposure of from 20 to 24 hours, will give excellent results at a cost of from 1 to 3 cents per 100-pound bag, including labor charges.

The mixture of carbon dioxide with methyl formate may be used at a dosage of 30 pounds per 1,000 cubic feet of space.

Hydrocyanic acid can also be used for fumigating nuts in atmospheric vaults, although it is not so popular for this purpose as ethylene oxide. A dosage of one-half pound of liquid hydrocyanic acid or its equivalent is required for each 1,000 cubic feet of space.

VACUUM FUMIGATION FOR NUT MEATS

For the vacuum fumigation of nuts the ethylene oxide-carbon dioxide mixture is excellent. A dosage of 30 pounds per 1,000 cubic feet for a period of from 1 to 2 hours gives satisfactory results at a cost of

from 3½ to 4 cents per 100 pounds of nuts. A mixture of carbon disulfide and carbon dioxide has been used in the vacuum treatment of nuts, but owing to the need for special equipment for applying it safely and to the fact that it is unsuitable for the treatment of pecans, Brazil nuts, and cashews, it is not recommended.

FUMIGATION OF SACKED PEANUTS IN FREIGHT CARS

Concerns resorting to freight-car fumigations of shelled sacked peanuts while the commodity is sidetracked at some transfer point can get the same protection more cheaply by insisting upon receiving from the railroad modern tight steel cars and fumigating the loaded cars on their own siding overnight. For this purpose hydrocyanic acid gas should be used at the rate of 1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of car space. Experiments have shown that in steel cars loaded according to common practice this gas gives good control when the ventilators and doors are well sealed. Fumigations in wooden cars are less satisfactory, and in very loosely constructed cars of little value.

FUMIGATION SCHEDULE FOR CANDY FACTORIES

The adoption of a regular fumigation schedule would largely eliminate insect losses in the candy industry. Infested raw materials and returned goods constitute the main sources of infestation in the factory. Insects from these sources spread all over the factory and lay eggs on the finished product. These eggs hatch after the candy is packed and produce costly infestations in packages that leave the factory apparently in good condition.

Every candy factory should have a fumigation vault or a vacuum chamber, and all returned goods should be fumigated before they are admitted to the factory. All incoming raw materials that are susceptible to insect attack, such as nut meats, cocoa beans, farinaceous materials, dried fruits, milk powders, and chocolate, should be rigidly inspected on their arrival at the plant and, if infested or suspected of being infested, should be fumigated before being placed in the main storage sections. If possible, raw materials should be stored away from the main part of the factory, and in sections that are adapted for separate fumigation.

DOSAGES

Returned goods and raw materials other than nut meats can be fumigated in tight vaults with one of the following fumigants at the dosages indicated per 1,000 cubic feet: Ethylene oxide, 2 pounds; ethylene oxide-carbon dioxide mixture, 20 pounds; methyl formate-carbon dioxide mixtures, 30 pounds; chloropicrin, 2 pounds; liquid hydrocyanic acid or its equivalent, 8 ounces; or methyl bromide, 1 pound.

Large storage sections can best be fumigated with hydrocyanic acid at the rate of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet.

As a general precaution it is advisable to fumigate the entire factory at least once a year. For this purpose hydrocyanic acid should

be used at the same rate as for the treatment of the large storage sections.

Furniture

Insect-infested furniture is usually fumigated in an atmospheric vault, although a vacuum vault can be used and is preferable in cases where infestation is due to wood-boring insects.

Hydrocyanic acid, ethylene oxide, carbon disulfide, chloropicrin, carbon tetrachloride, the mixture of carbon dioxide with ethylene oxide or methyl formate, and the ethylene dichloride-carbon tetrachloride mixture can all be used for the fumigation of furniture in atmospheric vaults.

Hydrocyanic acid and the ethylene dichloride-carbon tetrachloride mixture are used most commonly. A dosage of 8 ounces of liquid hydrocyanic acid or its equivalent, or of 14 pounds of ethylene dichloride-carbon tetrachloride mixture, per 1,000 cubic feet of space, for a period of 12 to 24 hours will give satisfactory results unless wood borers are involved, when the exposure should be at least 48 hours. If any of the other fumigants are used, the following dosages should be applied per 1,000 cubic feet of space: Ethylene oxide, 2 pounds; ethylene oxide-carbon dioxide mixture, 20 pounds; methyl formate-carbon dioxide mixtures, 28 pounds; carbon disulfide, 5 pounds; chloropicrin, 1 pound; or carbon tetrachloride, 30 pounds.

Furs and Garments

The protection of furs and fur and other garments in storage by fumigation is becoming more common. The method consists in storing garments in tight rooms (fig. 32) that are so arranged that they can be fumigated regularly. The garments are fumigated in a small vault (figs. 2 and 24) before being placed in the storage rooms (fig. 33).

CONSTRUCTION OF STORAGE ROOMS

The large storage rooms may be of any type of construction that is sufficiently tight for fumigation purposes. Usually they are of concrete or of hollow tile covered with Keen's cement. The surface should be finished with two or three coats of good paint. Large shallow evaporating pans are fastened along the walls near the ceiling, or are suspended from the ceiling, but so placed that they are not directly over the garments suspended from the racks. These pans are connected by pipes to the storage tank (fig. 34) containing the fumigant. If ethylene dichloride-carbon tetrachloride mixture is used as the fumigant, it can be run into the evaporating pans by gravity or by the use of a small compressor. If any of the mixtures of carbon dioxide with ethylene oxide, methyl formate, or methyl bromide is to be used, the evaporating pans are unnecessary, and a piping system with one or several spray nozzles or cones should be used instead. The cylinders containing one of these mixtures with carbon dioxide are connected to the piping system outside of the room (fig. 23), and the fumigant is applied by merely opening the valve on the cylinders and allowing the required poundage to be discharged.

The door of the storage room is usually of the safe or refrigerator

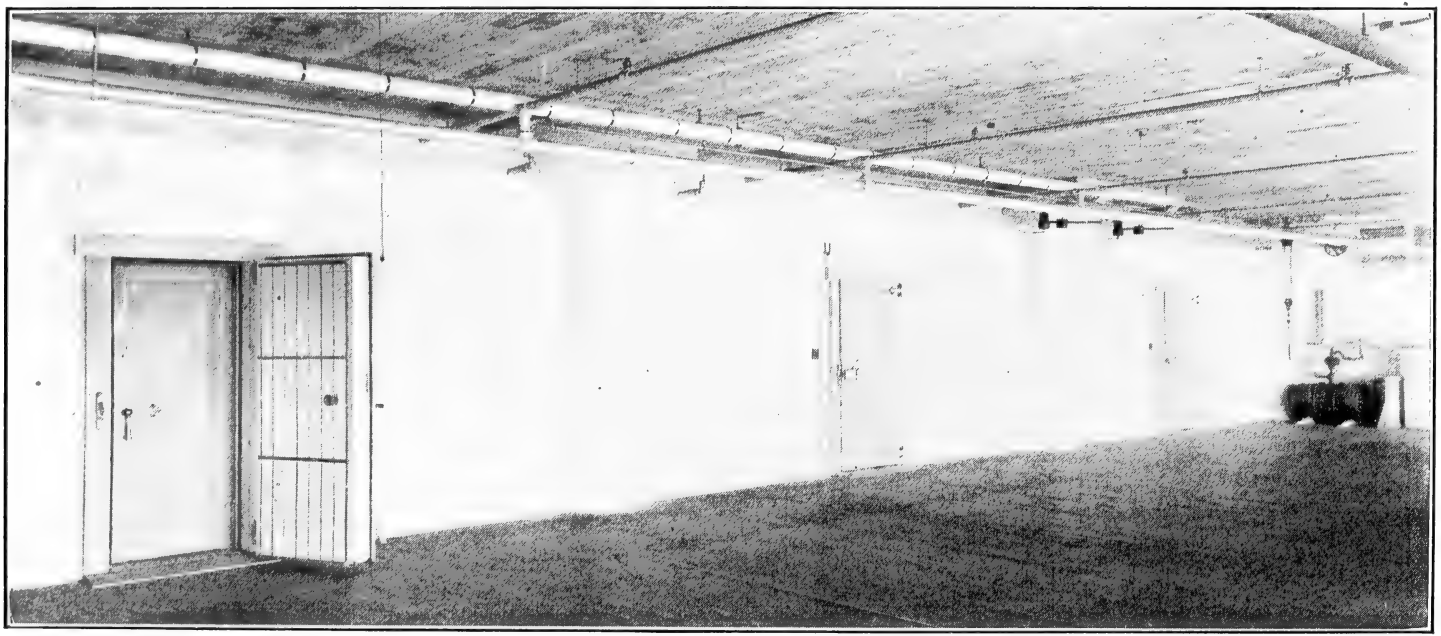

FIGURE 32.—Battery of three large fumigable fur-storage vaults constructed in a modern concrete building, equipped with devices for regulation of temperature and humidity, and for introducing and taking out the fumigant, as well as with burglar alarms. At right on warehouse floor, note storage for fumigant and pump for forcing fumigant to any room desired. These rooms have been operated successfully in southern California for more than 15 years.

type, well gasketed so that it will be airtight. An adequate ventilating system must be installed, so that the gas can be quickly removed after the fumigation. As in the case of small fumigation vaults, the ventilating stack should extend well outside the building.

In cold climates there should be some means of heating the storage room to at least 70° F. during the fumigation.

If it is necessary to enter the storage room while it is under fumigation, the operator should wear a gas mask equipped with a canister designed for protection against the particular gas that is being used and should remain in the room only long enough to obtain the garment needed. Where concentrations of gas beyond the capacity of a standard canister are likely to be encountered, the workmen should wear air-line masks with air supplied from a safe source and have all skin areas protected.

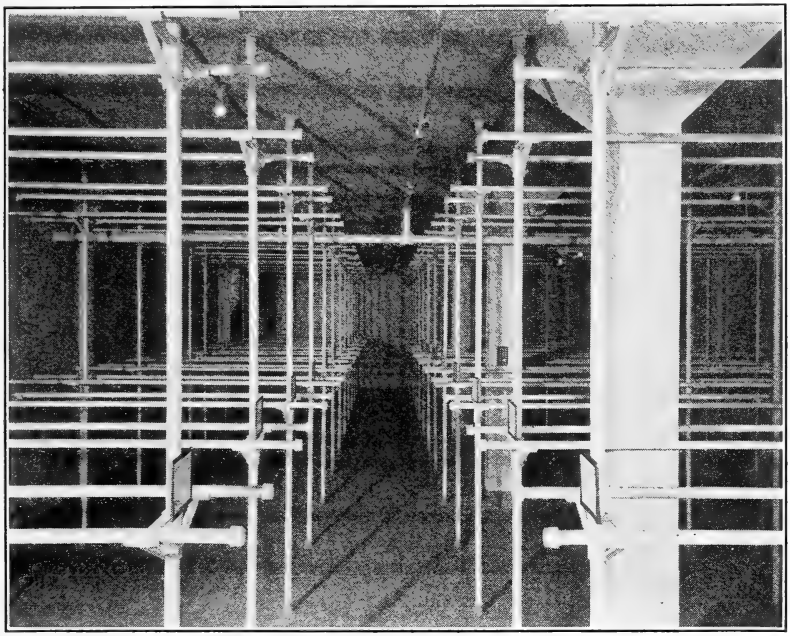

FIGURE 33.—Interior of fur-storage vault with racks installed for holding garments in best possible position for ready access and effective fumigation.

DOSAGES

For the fumigation of the large storage sections a dosage of 14 pounds of the ethylene dichloride-carbon tetrachloride mixture, 15 pounds of ethylene oxide-carbon dioxide mixture, or 30 pounds of a methyl formate-carbon dioxide mixture should be used per 1,000 cubic feet of space, with a week-end exposure.

For the preliminary fumigation of fur garments in small vaults the same fumigants and the same dosages recommended for the large storage sections can be used, although an exposure of 12 to 24 hours is sufficient.

EFFECT OF FUMIGATION ON FURS

Fur garments appear to be in no way affected by the vapors of the fumigants recommended, and dry storage has no deleterious effect upon the furs. A few instances of change in color of furs stored in fumigable storage have been reported, but in no case has this been clearly shown to be the result of fumigation. Thousands of dollars' worth of furs are being stored annually in fumigable storages throughout the country, to the satisfaction of all concerned.

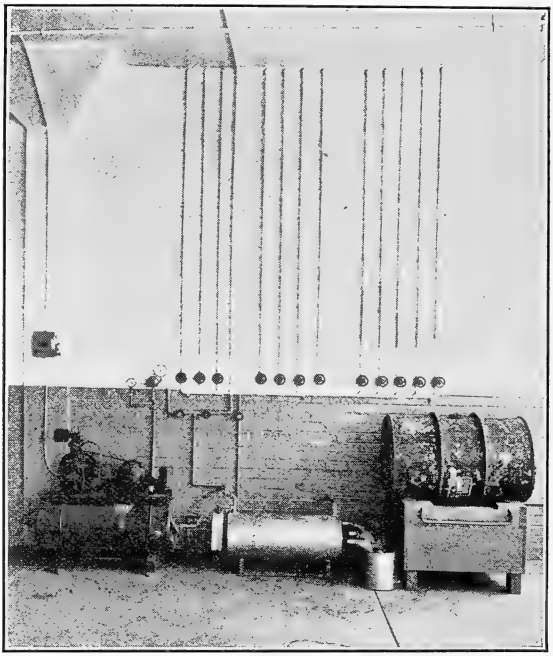

FIGURE 34.—Exterior view of commercial fur-storage vault equipped for fumigation with ethylene dichloride-carbon tetrachloride mixture. Note storage drum at right, pump at left, and pressure tank in center connected with various fumigating vaults, not shown, by pipe lines on wall.

RUGS AND TAPESTRIES

Rugs and tapestries in storage can be protected by the same methods and equipment that are recommended for the storage of furs. Many firms, however, prefer to use naphthalene flakes or paradichlorobenzene crystals in place of liquid fumigants. On exposure to air at ordinary room temperatures, both these solid fumigants give off a heavy vapor, which gradually permeates the atmosphere of the storage room. If a saturated atmosphere of either of these materials is maintained in the storage room, adequate protection from insects can be obtained (fig. 35).

At a temperature of 77° F., 8 ounces of paradichlorobenzene or 0.64 ounce of naphthalene is required to saturate the atmosphere in 1,000 cubic feet of space, where there is no opportunity for escape of vapors. Under ordinary storage conditions, however, it is advisable to use an

excess of these fumigants in order to counteract losses by absorption and leakage and to insure a continuously saturated atmosphere. In experimental work it has been found that a dosage of 1 pound of either flake naphthalene or paradichlorobenzene to each 100 cubic feet of space will cause fabric pests to cease feeding and to die after prolonged storage in tight rooms.

When no attempt is made to hasten evaporation by the application of heat, the vapors of naphthalene and paradichlorobenzene are not so quickly toxic to insects as are the liquid fumigants. Their chief value lies in the continuous protection that they afford. Since vapors are

FIGURE 35.—Rug-storage vault in which rugs are protected against fabric pests by vapors of paradichlorobenzene or flake naphthalene.

evolved but slowly from the crystals, one application may last for several months.

Light concentrations of the vapors of naphthalene and paradichlorobenzene have an irritating effect on the eyes and respiratory tract, making a person who has been exposed to them more susceptible to colds and other respiratory ailments. Higher concentrations are toxic and must be avoided.

DRIED FRUIT

Dried fruit is very susceptible to insect attack and must be protected from infestation at all times. Growers and packers usually find it necessary to fumigate dried fruit before it is stored, and for this purpose should equip themselves with fumigation chambers or fumigable storage bins (fig. 3). The fumigation of dried fruits under rubberized tarpaulins is reasonably effective. The fruit can be fumigated and then placed in an insect-tight storage section, or it can be placed directly in storage bins that are so constructed that they can be fumigated from time to time as needed. Any type of construction that is gastight is suitable for storage bins.

On ranches (figs. 25 and 26), where the fire hazard can be guarded against, carbon disulfide can be used. It is both cheap and effec-

tive. A dosage of 20 pounds per 1,000 cubic feet of space and an exposure of 24 hours at a temperature of 70° F. or higher will give satisfactory results.

In packing houses or storage sections where fumigation chambers or fumigable storage bins are not isolated, a fumigant that does not have the fire hazard of carbon disulfide is desirable. In such circumstances any of the following materials can be used at the dosages indicated per 1,000 cubic feet: Ethylene oxide, 2 pounds; ethylene oxide-carbon dioxide mixture, 20 pounds; methyl formate-carbon dioxide mixtures, 30 pounds; methyl bromide, 1 pound; chloropicrin, 1 pound; ethylene dichloride-carbon tetrachloride mixture, 20 pounds; or liquid hydrocyanic acid or its equivalent, 20 ounces. Hydrocyanic acid gas is absorbed in considerable quantities by dried fruit, but it is ordinarily quickly given off after the fruit is aerated.

TREATING THE FINISHED PRODUCT

It is sometimes desirable to fumigate the finished package before it is shipped. For this purpose a fumigation room or a vacuum tank is necessary. If a fumigation chamber is used, the fumigants and dosages recommended for the raw products can be used. If vacuum fumigation is resorted to, excellent results can be obtained with a dosage of 30 pounds of the ethylene oxide-carbon dioxide mixture per 1,000 cubic feet for a period of from 1 to 2 hours.

Carbon disulfide blanketed with carbon dioxide is frequently used for this purpose. Individual packages can be successfully treated in the packing line with methyl formate. From 5 to 9 cubic centimeters of this material is spattered into the bottom of the paper or paper-bag liner of 25-pound boxes of dried fruit. The fruit is then dropped into the box, the liner folded over, and the cover nailed or pasted down.

INFESTATIONS IN WAREHOUSES

Infestations that develop in storage warehouses can be handled by fumigating the infested fruit in a fumigation chamber or vacuum tank or by fumigating the entire storage section with hydrocyanic acid. If the entire storage section is fumigated, a dosage of from 8 to 20 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space should be used for a period of 24 hours. The dosage will depend on the tightness of the storage section and the quantity of fruit in storage.[7]

Cured Meats and Cheeses

Infestation of cured meats and cheeses by mites, ham beetles, or skippers frequently makes fumigation necessary. Meat-storage houses that are reasonably tight can usually be successfully fumigated with hydrocyanic acid at the rate of 1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet for a period of 24 hours. Such treatment does not injure the meats, but if the infestation has penetrated deeply into the meat, it is difficult to get a perfect kill. The

[7] Detailed information regarding the fumigation of dried fruit can be found in the U. S. Bureau of Entomology and Plant Quarantine Mimeographed Circular E–353, Dried Fruit Fumigation.

Federal meat-inspection regulations[8] require that permission for each fumigation be obtained from the Federal meat inspector.

Cheeses that are protected by an unbroken layer of paraffin can be safely fumigated with hydrocyanic acid, but, owing to the danger of their absorbing large quantities of the gas, unprotected cheeses should be removed from a warehouse that is to be fumigated.

For the treatment of small quantities of cured meats, or cheeses, a fumigation vault or other tight container is recommended. Carbon disulfide at the rate of 10 pounds, ethylene oxide at the rate of 2 pounds, or the ethylene oxide-carbon dioxide mixture at the rate of 20 pounds per 1,000 cubic feet of space can be used for a period of 24 hours.

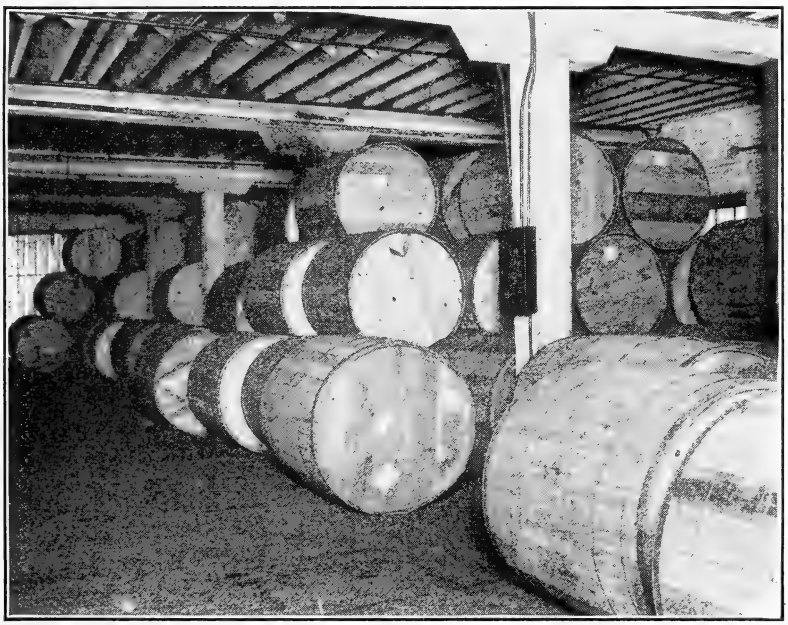

FIGURE 36.—Interior of tobacco storage with tobacco stored in hogsheads.

STORED TOBACCO[9]

Tobacco that is held in storage (figs. 36 and 37) often becomes infested with the cigarette beetle (*Lasioderma serricorne* (F.)) or the tobacco moth (*Ephestia elutella* (Hbn.)). If the infested tobacco is held in closed storage, fumigation with hydrocyanic acid gas is the most effective means of preventing further loss from insect attack.

Since the fumigants will not ordinarily penetrate tobacco hogsheads in killing concentrations deeper than from 3 to 6 inches, fumigations in warehouses should be timed to correspond with the emergence of the broods of insects. From May to November, when tobacco insects are normally abundant, it is desirable to suspend boards covered with

[8] U. S. Department of Agriculture, Bureau of Animal Industry, Service and Regulatory Announcements, January 1921, p. 3, and August 1927, p. 62.

[9] More detailed information on the fumigation of tobacco warehouses will be found in U. S. Department of Agriculture Circular 635, Control of Insects Attacking Stored Tobacco and Tobacco Products.

fly paper under electric lights in warehouses to serve as indicators of the abundance of the insects. Whenever 50 adult cigarette beetles or 30 adult tobacco moths are caught on one indicator in a week, it is well to fumigate.

Two or more fumigations are usually required in one season. For light to moderate infestations a dosage of 10 ounces of liquid hydrocyanic acid or its equivalent should be applied, whereas heavy infestations should receive 16 ounces per 1,000 cubic feet. The exposure should be for 72 hours if this does not interfere with warehouse routine.

For the fumigation of tobacco factories a dosage of 8 ounces of

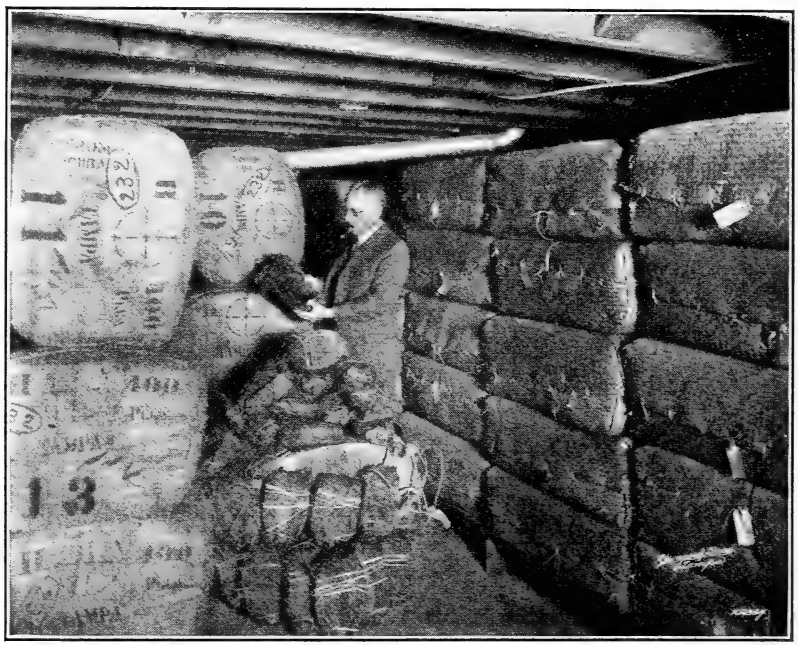

FIGURE 37.—Tobacco in bales and stacked as closely as shown here cannot be fumigated satisfactorily by ordinary atmospheric fumigation. The bales should be either more loosely stacked or removed to vacuum chambers for fumigation.

liquid hydrocyanic acid or its equivalent per 1,000 cubic feet for a period of 24 hours is sufficient.

To keep down infestation in tobacco factories, many firms fumigate all incoming tobacco in atmospheric vaults or vacuum chambers.

For use in atmospheric vaults hydrocyanic acid at a dosage of 10 ounces of liquid hydrocyanic acid or its equivalent, ethylene oxide at the rate of 2 pounds, ethylene oxide-carbon dioxide mixture at 20 pounds, or carbon disulfide at 10 pounds per 1,000 cubic feet of space should be used for a period of from 48 to 72 hours. Carbon disulfide should not be used unless the vault is isolated from the rest of the buildings and the fire hazard can be controlled. The fumigation of an entire tobacco warehouse with carbon disulfide is a dangerous procedure and is not recommended.

For the vacuum fumigation of tobacco (figs. 27 and 28) the following dosages per 1,000 cubic feet are recommended:[10] Ethylene oxide-carbon dioxide mixture, 60 pounds for 4 hours or 55 pounds for 15 hours for imported cigarette types, 50 to 55 pounds for 4 hours or 45 to 50 pounds for 15 hours for cigar-filler, 65 pounds for 4 hours or 60 pounds for 15 hours for cigar-wrapper, and 45 pounds for 4 hours for manufactured cigars; liquid hydrocyanic acid, 5 pounds for 4 hours or 4 pounds for 15 hours for imported cigarette types, 4 pounds for 4 hours or 3 pounds for 15 hours for cigar-filler, and 5 pounds for 4 hours or 4 pounds for 15 hours for cigar-wrapper tobacco.

Flour[11]

For controlling insects in flour mills and reducing insect damage to milled products, some form of fumigation is usually practiced. Many millers are satisfied with one general fumigation a year, others may supplement the general fumigation with local or spot fumigations, while some find it profitable to have several general fumigations a year in addition to a regular schedule of local fumigations.

GENERAL MILL FUMIGATION

General fumigations may be conducted by introducing all the gas into the open space of the mill, by introducing all the gas into the machinery, or by introducing a portion into the machinery and the rest into the open mill space. Hydrocyanic acid, chloropicrin, and methyl bromide can be used successfully in mill fumigation, although hydrocyanic acid is used most extensively.

FUMIGATION WITH HYDROCYANIC ACID

Open-Space Method

Preparing the Mill.—When all the fumigant is to be introduced into the open mill space, it is necessary to dismantle the machinery and make special preparations to insure a good kill. In addition to the regular procedure for preparing a building for fumigation, the directions given below should be followed:

Before Stopping the Mill

1. Shut off feed (wheat) at mixing bin.
2. Continue running all machinery until material is emptied from spouts, elevators, conveyors, rolls, sifters, reels, purifiers, feed dusters, suction trunking, and dust collectors.
3. Remove elevator-boot slides and station men along the boots to keep stock pulled out where belt cups will not carry it up.
4. Meanwhile, hammer elevator legs, machinery, frames, tubular dust collectors, and spouts with a rubber mallet or other device which will not bruise or injure the equipment.

After Stopping the Mill

1. Open all machines, conveyor boxes, and flour bins.
2. Remove covers of all conveyors, making certain that all dead-end spaces are readily accessible.
3. Thoroughly clean all conveyors, including dead-end spaces.
4. Clean out accumulations from bottom section of the bran duster.

[10] See footnote 9.

[11] Further information on the fumigation of flour mills may be obtained from U. S. Department of Agriculture Circular 390, revised, Flour-Mill Insects and Their Control.

5. Clean all elevator belting that may be webbed; drag spouts of same.
6. Remove the adjustible feed gage above grinding rolls and clean out accumulations above rolls and feeders.
7. Examine tubular dust collectors and clean out all accumulations.
8. Clean out suction trunks, conveyors, and dust-collector systems.
9. Open dust collectors, back drafts, main trunks, and hand openings.
10. Loosen all sifter doors to permit entrance of gas during fumigation; remove sieves and stack on floor.
11. Leave every machine open; also all hand openings to spouts, elevator legs, etc.
12. Remove and burn all infested materials accumulated in cleaning the mill.
13. All infested lots of flour and other milled products should be removed (or reconditioned) before cleaning the mill. These products should not be returned.
14. If the above procedure is followed, no accumulation more than 1 inch in depth will be present in the mill.
15. Special attention should be given to the cleaning of the dead spouts and dead spaces in corners of spouts and machines.
16. Remove all bags and other materials used to plug spouts.
17. Seal roof ventilators or replace mushroom-shaped cap with a tight metal cap.

Dosage and Method of Generation.—In general, a dosage of 8 ounces of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space has been found most satisfactory for flour-mill fumigation. All the methods that have been described for generating this gas may be used with good results. With the miller who does his own fumigating the pot or barrel method is popular, but professional fumigators prefer to use liquid hydrocyanic acid and avoid the labor of handling barrels, water, and acid. Regardless of the method of generation, the gas is the same, and if the mill has been properly prepared excellent results can be expected.

Distribution of the Fumigant.—To obtain quick equalizing of the fumigant, it should be evenly distributed throughout the mill, except that floors containing more machinery than others should receive a heavier dosage. With all methods of application gas concentrations soon become uniform throughout the mill.

Length of Exposure.—In the average mill heavy concentrations of the gas can be maintained only for a very short period; hence an exposure of from 10 to 24 hours is usually all that is practical.

Machinery Piping Method

Recently a method has been developed by which hydrocyanic acid is applied directly into the milling machinery instead of into the open mill space. A series of pipe lines connects each piece of machinery with a manifold outside the mill. Spray nozzles that open at a set pressure deliver uniform quantities of fumigant to each piece of equipment, and when the pressure is removed they close automatically so that they cannot be clogged with milling stock between fumigations.

By applying the fumigant directly into the machinery, concentrations high enough to penetrate the stock left in the milling equipment are obtained with a smaller quantity of gas; hence it is unnecessary to dismantle and clean out the machinery. The saving in time, labor, and fumigant makes it possible to fumigate twice as often as by the open-space method at no greater cost.

Although it is unnecessary to follow the procedure recommended for open-space fumigation, there are a few rules that should be followed in preparing the mill for fumigation.

PREPARATION OF THE MILL.—The grain feeder or regulator above the first break should be closed and the mill allowed to run. The entire mill crew should be given rubber mallets and assigned the task of hammering slide spouts, cleaning feed gates and suction lines, and moving as much accumulated stock into the mill stream as possible.

As soon as the rolls are opened after the feed has been shut off, the elevator-boot slides should be pulled up and the accumulations of milling stock pulled out of reach of the belt cups.

The mill should be run for an additional 15 minutes to remove as much milling stock as possible.

After the mill has been shut down, the roof vents from the cyclone dust collectors should be tightly sealed. This is extremely important, since the cyclone dust collectors are directly connected with almost all machines. The best method is to remove the mushroom-shaped caps and replace them with tightly fitting metal caps. Covering the vents with paper or combinations of paper and burlap or tarpaulin is not entirely satisfactory and is not recommended.

Sifter sections should be removed, the stock on the sieves deposited on the floor, and the sieves replaced. The doors in sifter sections should be replaced, but not tightly enough to prevent free circulation of the gas.

Accumulations behind the feed gates of the purifiers should be removed, and the feed gates tied or blocked open to allow free passage of the gas into the slide spout carrying stock to the purifier.

Dividing gates below the cant boards of both reels and purifiers should be exactly vertical to allow equal distribution of the gas into the different conveyors. Stock in the end of these conveyors beyond the reach of the flights should be removed, together with any packed accumulations more than 3 inches deep.

Accumulations above the feed gates of the purifiers should be moved. The roll housings should be cleaned and the feeder gates blocked open to allow the gas to reach the feeder-gate roll housing and slide spouts above.

Where Buckley grinders are used, the hand lever should be raised, thus compressing the driving spring and separating the grinding surfaces to allow free passage of the gas through the mechanism.

The final operation should consist of checking all units to see that all machines are closed. Accumulations removed from elevator boots or other machinery should be cleaned up, bagged, and placed in a fumigation or heating vault for treatment.

Windows and doors should be closed but need not be sealed. Broken sash should be replaced.

TESTING THE FUMIGATION LINES.—Air pressure should be applied to the piping system, and each spray nozzle examined to see that it is working properly. Leaky connections can be detected and tightened.

APPLICATION OF THE GAS.—The liquid hydrocyanic acid is forced into the various lines at the rate of 6 to 8 ounces for each spray nozzle on the line. The standard hydrocyanic acid cylinder has too small an opening to allow the gas to be put into the fumigation lines with sufficient pressure to insure uniform distribution. A special applicator is therefore utilized, which consists of a small steel tank holding 35 pounds of liquid hydrocyanic acid and capable of withstanding a working pressure of 200 pounds. A gas-outlet valve on the top-central part of the cylinder is connected with a half-inch copper

tube extending to the bottom of the tank. This tube is larger than that of the shipping cylinder and allows the more rapid flow of gas needed. Gas-inlet valves (half-inch brass) and a pressure gage are also located on the top-central part of the cylinder. From the tank connection of the gage a bypass of quarter-inch copper tubing supplied with a valve is connected to the gas-outlet line between the outlet valve and the manifold of the piping system of the building being fumigated. This bypass allows the pressure developed by the transfer of the hydrocyanic acid from the shipping cylinder to the applicator to escape into the manifold, thus facilitating the filling of the applicator.

CHLOROPICRIN AS A MILL FUMIGANT

For fumigation with chloropicrin the mill should be prepared in the same way as for fumigation with hydrocyanic acid, except that items 1 to 14 of the directions for preparing the mill after the machinery is stopped can be omitted. Each piece of machinery is treated separately, and in addition the open space of the mill is treated at the rate of 1 pound of chloropicrin per 1,000 cubic feet.

Sufficient data have not yet been obtained for making definite recommendations of dosages to fit the varying conditions encountered in general mill fumigation. As a rule, however, the following dosages recommended by the manufacturers of chloropicrin will give satisfactory results:

Dosage Table for Treating Milling Machinery

All bins, including packer bins, feed and bran bins, and screening bins	1 pound per 1,000 cubic feet.
Elevator legs	8 to 9 ounces each, in upstream side.
All reels, purifiers, dusters, scourers, and conveyors	5 to 6 ounces each.
Square sifters	2 to 3 ounces each.
Rolls	1 ounce each.
Separators	2 to 3 ounces each.
Flour agitators	2 ounces each.
Grinders for screenings and bran	2 ounces each.
Buhr mill	2 ounces.

The proper quantity of chloropicrin for each floor of the mill should be measured out from the 100-pound cylinders into quart glass bottles or gallon containers and distributed before the fumigation is begun. The measuring should be done outside the building so that the fumes will be dissipated in the open air. However, men doing the measuring or handling the chemical should wear gas masks equipped with the proper canisters for this gas. The quart bottles should be graduated so that the correct dosage for each piece of machinery can be applied quickly. One pound of chloropicrin equals 9¼ fluid ounces.

The fumigators start at the top of the mill and work down, treating all the machinery and leaving the elevator boots until the last. **Each fumigator must wear a mask equipped with a canister especially adapted to protect against the vapors of chloropicrin.**

The machinery is treated by sprinking from the quart bottle directly inside each machine or, if this is impractical, by pouring it in through a hole in one end. Aluminum sprinkler corks can be attached to the bottles as they are used. In open mill space the

chloropicrin is sprinkled on burlap sacks spread out on the floor, 6-quart sprinkling cans being convenient for this purpose.

Care should be taken not to spatter the liquid on the hands or feet, since it might cause blistering of the skin.

Where conditions in the mill do not warrant a general fumigation, satisfactory results can sometimes be obtained by fumigating the machinery only. For this type of fumigation the chloropicrin is applied directly into the machines in accordance with the dosage table. The dosage for the reels and purifiers should be increased in proportion to the quantity of stock left in the machinery. In general, at least 1 pound should be used in each machine.

Considerable time is required to ventilate a building that has been fumigated with chloropicrin, as evaporation is slow and the fumigant clings to commodities with great tenacity. When present in flour, chloropicrin has a deleterious effect on its baking quality, but this effect disappears when the flour is aerated.

METHYL BROMIDE AS A MILL FUMIGANT

For fumigation with methyl bromide the mill should be prepared in the same manner as for an open-space fumigation with hydrocyanic acid except that it is unnecessary to clean out the stock from the milling units. In fact, better results are obtained if the milling stock is left. This is a distinct advantage in that the cost of cleaning out and removing the stock is avoided.

As far as practical each floor should be treated as a separate unit, doors between floors and to stair wells and freight elevators being closed. Some interchange of gases through the slide spouts and elevator legs is unavoidable.

The gas should be used at the rate of 1 pound per 1,000 cubic feet of space, and it should be applied through the same type of piping system employed with liquid hydrocyanic acid in open-space fumigation. If the floors of a mill can be closed off, the dosage should be divided equally. Otherwise slightly more of the gas should be applied to the upper floors, since the gas is heavier than air. As previously described, the gas is applied from cylinders that are connected to a manifold on the outside of the mill. The pressure in each cylinder is increased to 150 pounds with compressed air, the valve is opened, and the gas flows rapidly through the piping system into the mill.

After a 16- to 24-hour exposure the mill can be opened up for aeration. **Workmen opening up the mill should wear masks equipped with a canister designed to protect against the vapors of methyl bromide.** Ordinarily the vapors clear out rapidly.

Owing to the absorption and retention of the methyl bromide by the milling stock, it is well to set aside the first 24 bags of flour for each 500-barrel unit after the mill is started. Later this flour can be gradually fed back into the mill.

LOCAL FUMIGATION

A general fumigation once or twice a year does not entirely solve the insect problem in a flour mill, since small infestations are continually developing here and there throughout the milling system.

Many millers guard against these infestations by establishing a regular schedule of local fumigations, or treatment of individual machines. Local fumigations can be conducted on week ends or any night after the mill is shut down. Chloropicrin, hydrocyanic acid, and the ethylene dichloride-carbon tetrachloride mixture are used extensively for this purpose.

FUMIGATION WITH CHLOROPICRIN

Chloropicrin is used in local fumigations in the same way as described for general fumigations, except that the individual machines are sealed off from the others. **The fumigator should, of course, wear a gas mask.**

FUMIGATION WITH ETHYLENE DICHLORIDE-CARBON TETRACHLORIDE MIXTURE

The ethylene dichloride-carbon tetrachloride mixture is applied by spraying or pouring it into the individual units at the following dosages:

Purifier and reels	16 to 29 ounces in each conveyor.
Sifters	12 ounces in each section.
Flour conveyors	1 to 2 ounces per linear foot.
Elevator boots	12 ounces.
Elevator heads	12 ounces to each leg.

Other machinery in proportion to size.

FUMIGATION WITH HYDROCYANIC ACID

Hydrocyanic acid can be applied in several different ways. The same safety precautions should be taken as in a general fumigation. **Workmen handling the material should be equipped with gas masks and all others kept out of the mill.**

The machines should be prepared by cleaning out all accumulations as outlined in the directions for preparing a mill for a general open-space fumigation. Machines treated separately should be sealed off and made as tight as possible.

Calcium cyanide containing 22 to 28 percent of available hydrocyanic acid is frequently used for this purpose and is easily applied. A dosage of about 12 ounces for each machine is applied to rolls, purifiers, and sifters. It is spread evenly on dry newspapers in the lower part of the machine. If sifters are equipped with blanks, they should be removed from one section or opening to allow free circulation of the gas. All machines should be made as tight as possible, sheets of wrapping paper being placed behind the ventilating doors on the sides of the purifiers. Each elevator leg should be treated with 2 ounces of the calcium cyanide.

Calcium cyanide containing 51 to 52 percent of available hydrocyanic acid is also used for local fumigation work and is applied by means of the special apparatus illustrated in figure 38. This machine draws in calcium cyanide dust through a blower intake, mixes it with air and moisture, and blows the liberated hydrocyanic acid gas through the outlet hose into the elevator legs, spouts, conveyors, rolls, reels, purifiers, and other milling equipment. The dust is retained inside the machine. A dosage of 2 pounds of calcium cyanide is sufficient for treating four elevator legs and connected spouts and grinders, or six ordinary milling machines.

One outlet hose from the machine is inserted in each of two elevator legs, and the blower is operated for about 10 minutes. The hose is then moved to two other elevator legs and the blower operated for 15 minutes.

Windows in the mill should be kept open during the fumigation and for 3 hours thereafter to allow the fumes to escape.

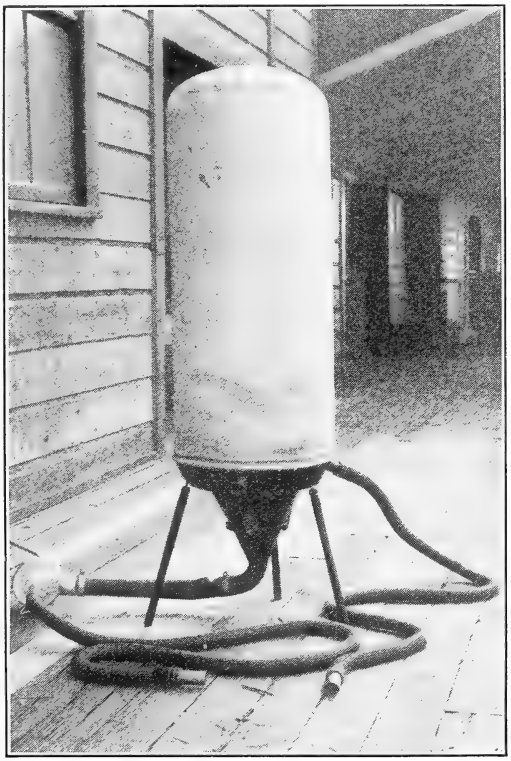

FIGURE 38.—Apparatus for passing air through calcium cyanide dust in such a way that the hydrocyanic acid gas evolved will be free from the dust.

FUMIGATION OF FLOUR WAREHOUSES

Warehouses containing flour, feed, or other cereal products often become infested. In the average well-filled warehouse it is impossible, on account of the absorbent nature of these commodities, to obtain a complete kill with any fumigant except methyl bromide. This fumigant is effective in tight concrete or brick warehouses at a dosage of 2 pounds per 1,000 cubic feet, but it is useless in loosely constructed warehouses. It is not recommended, however, for the treatment of milled cereal products intended for human consumption, owing to the retention of large quantities of residual bromides by these products.

In loosely constructed warehouses hydrocyanic acid can be employed for general clean-up purposes and to kill insects in the open space and in the outer portions of bagged materials. A dosage of

1 pound of liquid hydrocyanic acid or its equivalent per 1,000 cubic feet of space with an exposure of 24 hours will suffice for this purpose. The warehouse should be prepared for fumigation in accordance with the instructions given on page 6.

VAULT FUMIGATION FOR FLOUR OR CEREAL MILL

For the treatment of used bags, returned goods, or small lots of infested flour or cereals, a fumigation vault is almost essential. The vault can be of any of the types discussed on page 29. If possible, it should be located in a building separate from the main mill, so that used bags or returned goods can be fumigated before being taken into the main building.

Used bags can be fumigated successfully with any of the materials recommended for vault fumigation, and at the same dosages.

Bagged flour is fumigated with difficulty, owing to the excessive absorption of the gas by the outer layers of flour. In vault fumigations, when the vault is loaded to 25 percent of its capacity or more, the dosage should be based on the weight of the flour to be treated. A dosage of 12 ounces of liquid hydrocyanic acid or its equivalent per ton of flour should be used for an exposure of from 24 to 48 hours if the temperature of the flour is 80° F. or above.

For the fumigation of bagged feed or other milled cereals intended for animal feeds, methyl bromide can be used at a dosage of 1 pound for the first ton plus 2 ounces for each additional ton.

VACUUM FUMIGATION OF FLOUR PRODUCTS

For the vacuum fumigation of flour products at temperatures above 70° F., it is recommended that 2 ounces of liquid hydrocyanic acid per ton be used for an exposure of 3 hours with an absolute pressure of 2 inches or less. The ethylene oxide-carbon dioxide mixture can also be used successfully under the same conditions with the following exposures and dosages: 3 hours, 10 pounds per ton; 6 hours, 4 pounds per ton; 12 hours, 3 pounds per ton. In all cases the gas should be circulated for 15 minutes after it is introduced.

For animal feeds, 4 pounds of methyl bromide per 1,000 cubic feet of space for 3 hours or 3 pounds for 15 hours in filled vaults is satisfactory.

Rice [12]

Rice is grown and stored in the South, where it is subject to the attack of many of the worst insect pests of stored cereals. It can, however, be successfully fumigated with a wide variety of materials.

For atmospheric fumigation the following dosages of materials can be used per 1,000 cubic feet of space: Liquid hydrocyanic acid or its equivalent, 1½ pounds; chloropicrin, 2 pounds; methyl bromide, 1 pound; ethylene dichloride-carbon tetrachloride mixture, 20 pounds; or ethylene oxide-carbon dioxide mixture, 20 pounds. These dosages are based on an exposure of 24 hours with the temperature of the rice 70° F. or above.

Vacuum fumigation is particularly useful in the treatment of rice,

[12] Detailed information on the fumigation of stored rice will be found in U. S. Department of Agriculture Farmers' Bulletin 1906, Insect Pests of Stored Rice and Their Control.

and the following dosages are recommended per ton of rice with a vault one-half full or more: Liquid hydrocyanic acid, 2 ounces for 3 hours; methyl bromide, 3 ounces for 2 hours or 1½ ounces for 3 hours; and ethylene oxide-carbon dioxide mixture, 2½ pounds for 1 hour or 1½ pounds for 3 hours. These dosages should be used with an initial absolute pressure of 2 inches, and the fumigant should be circulated in the vault for 15 minutes. If the vacuum vault is not equipped for circulating the gas, the dosages should be increased by one-third.

Cottonseed Meal

Cottonseed meal, stored in 100-pound sacks, if held in certain storages during the summer following grinding, may become seriously infested with the cigarette beetle (*Lasioderma serricorne*). The infestation by this insect in commercially valuable meal is limited chiefly to the outer 2 or 3 inches, whether it is stored in sacks or in bulk. If market conditions indicate that the meal will be carried over the summer, losses resulting from rebates, regrinding, and resacking can be prevented by fumigation. If insects are already very abundant in meal stored in reasonably tight warehouses, one thorough fumigation with hydrocyanic acid gas, at the rate of 1 pound of sodium cyanide or its equivalent per 1,000 cubic feet of space, will kill from 95 to 97 percent of the insects. The small percentage escaping this treatment, however, may represent so many in numbers that a second fumigation 3 or 4 weeks later with one-half pound of sodium cyanide per 1,000 cubic feet will be desirable. One fumigation, conducted when the cigarette bettles are first noticed, will usually give a practical control for the summer and fall months provided there is no reinfestation from flying beetles from neighboring meal storages. An early treatment prevents destruction of the sacks, and the cost of labor and new sacks in repacking. The above-mentioned dosages are based on experimental fumigations. They are sufficient only for practical control and not for complete eradication.

SAFEGUARDS TO BE EMPLOYED IN FUMIGATION WORK

In all fumigation work the person in charge should not only acquaint himself with the dangers involved, but should bring his assistants together and explain to them the need for caution, and what should be done in case difficulty arises. He should know the first-aid recommendations issued by the manufacturers of the particular fumigant he is about to use. He should employ only men known to be dependable. Members of the fumigating crew should be in good physical condition, with minds alert so that they can act calmly and rapidly and work together according to a prepared and rehearsed plan of procedure. They should abstain from the use of intoxicants. They should take no chances.

All persons except fumigators should leave the building. When an entire building, or any floor, is to be fumigated, all persons in the entire building should be notified in advance and told that they must leave the building between certain specified hours. In large establishments the owners should be held responsible for keeping persons out of a building unless they have a definite agreement with the

fumigator that he assume all responsibility connected with the safe conduct of the fumigation.

It is not always necessary, or desirable, for persons to leave certain buildings while vaults or similar limited areas are under fumigation. Much depends upon the fumigant used, the type of building, and the methods employed for ventilation. The informed fumigator is in a position to determine what action is necessary. Many routine vault fumigations are conducted daily in congested city areas without danger to human life. It is good practice to keep vaults locked during fumigations. If warning signs are left in place permanently, workers may not notice them.

Where a piping system is used to apply a liquid fumigant in a vault, the outside assembly of valves may be enclosed in a wire cage provided with a padlock. Stocks of chemicals used for fumigations should be locked, preferably in a cool place away from main buildings.

Danger signs should be posted. Placards calling attention to the fact that a fumigation is being conducted and warning persons to keep out should be posted on all outside doors of the building.

Guards for buildings are desirable. Guards should be stationed outside buildings, to make certain that they are not heedlessly entered while being fumigated with a dangerous vapor.

FIRST AID FOR POISONING FROM HYDROCYANIC ACID GAS

Inhaling hydrocyanic acid gas or absorbing it through the skin is dangerous and must be avoided. If it is absorbed by the system, prompt steps to counteract its action must be taken. Any one or several of the following symptoms may indicate poisoning:

(1) Weakness or palpitation of the heart.
(2) Headache or dizziness.
(3) Rushing of blood to the head.
(4) Weakness or heavy feeling in the limbs and joints.
(5) Nausea and vomiting.
(6) Difficulty in breathing, contraction of the chest.
(7) Fainting and unconsciousness.

At the first slight indication of any of these symptoms a fumigator should warn his coworker, and they should both immediately leave the building and remove their masks in the fresh air. This makes certain that the affected person reaches the fresh air safely. Men have been known to start for the exit only to become unconscious en route, and if this happens the assistance of the coworker is necessary. If on reaching the outside the affected person is found to be only slightly affected, he can be left alone until he has fully recovered, while the coworker, with another member of the fumigating crew, returns to complete the work. If, however, a fumigator has difficulty in walking, becomes unconscious, or is appreciably affected in other ways, he should be hastily removed from the building to the open air and immediate provision made to keep him warm. Someone should be assigned to determine the reason for the failure of the gas mask, as outlined later in this section.

Gas masks should be available. Gas masks should always be worn during fumigation with hydrocyanic acid gas, methyl bromide, chloropicrin, or any other quick-killing fumigant.

Ethylene oxide, methyl formate, ethylene dichloride, carbon disulfide, and carbon tetrachloride, either alone or in the combinations usually recommended for fumigation work, are regarded as only slightly toxic to man as he ordinarily comes in contact with their vapors, **although gas masks must always be worn if the fumigators must remain exposed for appreciable periods.**

Approved gas masks, or commercial masks and canisters designed to protect against the gas being used, are intended only for use around fumigation operations and around equipment used outside the bin or building and in places where light concentrations only may be encountered. **They are not guaranteed to protect the wearer against high concentrations of any fumigant. Where it is necessary for human beings to enter places where high concentrations are present, only an air-line mask supplied with air from a safe source will afford complete protection. It is urged that this type of mask be used in all places where concentrations higher than 2 percent may be encountered.**

Gas masks should be cleaned and sterilized after each use, particularly if it is likely that several people may wear them. Each mask must be tested for leaks each time it is put on, by stopping up the canister connection and drawing in the breath. If the facepiece leaks, it should be adjusted to fit so that the normal movement of the head will not cause it to leak.

Besides wearing a gas mask, a fumigator should protect the entire skin area if it is necessary to remain in the gas for more than 5 minutes. Ordinary clothing affords little protection, as it will absorb the gas. Coveralls made of "slicker" material, with a hood fitting tightly around the gas mask, fastened tightly around the feet and ankles and fitting tightly around the wrists over the wrists of oiled leather gloves, constitute the best light-weight protection so far designed.

Never assume that a gas mask will protect. Obtain definite assurance that it is equipped with a canister of chemicals prepared to neutralize the vapor or vapors to be used. Attach a fresh, unused canister to the mask unless the exact history of the one already attached is known. Do not use a canister longer than the period recommended by the manufacturer or after it show signs of deterioration. Canisters for gas masks cost only about $2 each; there is no need to take chances. Do not permit familiarity with a dangerous fumigant to lead to criminal carelessness.

When a fumigator has left a building because of trouble with his mask, the men and their supervisor should seek the cause of the trouble. The gas mask should be cleaned and inspected, and then tested for leaks by putting on the mask, holding the hand tightly over the canister opening, and inhaling. If air is drawn in, the mask leaks and the leak must be found. Adjusting the facepiece should be tried first. If this fails to stop the leak, then the mask should be discarded or sent to the factory for repairs.

If the mask can be adjusted until it does not leak, a new canister can be attached and the mask will be ready for use. However, if the facepiece shows no leaks, and there is no leak in the canister connections, there are three other possible causes: (1) The canister may have been used too long; (2) the concentration of gas may have been higher

than the capacity of the canister; (3) the gas may have been absorbed through the skin.

Records must be kept to show how long the canisters have been in use. The length of time the men slightly affected during fumigation operations were in the gas should also be definitely known. If this was only a few minutes and the canister is a good one, the concentration of gas was too high for the canister.

It must always be remembered that concentrations of hydrocyanic acid gas too slight to be detected by any commercial instrument may still be deadly to human beings. Every effort must be used to keep men from breathing even very slight concentrations of the gas, as industrial medical men agree that the irritation of the respiratory passages makes a person much more susceptible to respiratory diseases.

Many commercial fumigators think that a man partially overcome by hydrocyanic acid gas should be exercised vigorously. According to Henderson and Haggard, however, **a gassed man should under no circumstances be allowed to exercise.** "He should neither walk nor even sit up, but must be kept recumbent and as quiet as possible until all symptoms have passed off."

He should not be given hypodermic injections or alcoholic stimulants. No liquids should be given by mouth unless the patient is fully conscious. He should not be allowed to return to work until he has fully recovered from the effects of the gas.

If the patient has ceased breathing, artificial respiration should be begun immediately, with use of the Shaefer prone-pressure method described below.

Shaefer Prone-Pressure Method of Artificial Respiration [14]

1. Lay the patient on his belly with his face to one side so that his nose and mouth are free for breathing. Place one of his arms straight out beyond his head and the other under his head, with both hands flat and palms down.

2. Kneel, straddle one of the patient's thighs, and face his head; rest the palms of your hands on his loins with your thumbs along the index fingers and with fingers spread over lowest or floating ribs.

3. With your arms held straight, swing forward slowly for about 3 seconds so that the weight of your body is gradually, not violently, brought to bear upon the patient.

4. Then, leaving your hands in place, swing backward slowly so as to remove the pressure, thus returning to the position noted in paragraph 2. Then remove the hands to allow the ribs to expand quickly, filling the lungs with air. Swing slowly backward to upright position, thus relieving the muscles of the back.

5. Repeat deliberately 12 times per minute, swinging forward and backward without interruption until natural breathing is restored or until the doctor arrives.

Artificial respiration should be continued 3 to 4 hours if necessary.

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[13] Henderson, Y., and Haggard, H. W. Noxious Gases, p. 159. New York, 1927.

[14] These directions are summarized from those given by other authors. Complete authentic information concerning this method can be obtained from the U. S. Public Health Service, Washington, D. C.

Loosen all tight clothing about the patient's neck, chest, or waist and keep him warm by whatever means are available.

Next to artificial respiration, the inhalation of a mixture of oxygen and 5 percent of carbon dioxide is most useful in resuscitation. By use of a specially designed inhalator the mixture of oxygen and carbon dioxide should be administered for from 20 to 30 minutes immediately after a man is removed from the gas or as soon thereafter as possible.

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